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(54) Title: MICROWAVE SINTERING

(57) Abrégé/Abstract:
A carbide composite that includes carbide particles having an average particle size of less than about 100 nanometers and a metallic binder disposed around the carbide particles is disclosed. The carbide composite may also include carbide particles having an average particle size ranging from 3 to 10 microns.

ABSTRACT

A carbide composite that includes carbide particles having an average particle size of less than about 100 nanometers and a metallic binder disposed around the carbide particles is disclosed. The carbide composite may also include carbide particles having an average particle size ranging from 3 to 10 microns.

MICROWAVE SINTERING

Cross-Reference to Related Applications

[0001] This application claims priority, pursuant to § 119(e), of U.S. Patent Provisional Serial No. 60/739,703 filed on November 23, 2005, which is herein incorporated by reference in its entirety.

BACKGROUND OF INVENTION

Field of the Invention

[0002] The invention relates generally to applications for microwave sintering. More specifically, the invention relates to microwave sintered cutting elements for use in drilling applications.

Background Art

[0003] Drill bits used to drill wellbores through earth formations generally are made within several broad categories of bit structures, including roller cone bits, and drag or fixed cutter bits.

[0004] Roller cone rock bits include a bit body adapted to be coupled to a rotatable drill string and include at least one "cone" that is rotatably mounted to the bit body. A plurality of cutting elements are positioned on each cone. Within the category of roller cone bits, there are two further categories, based on the type of cutting elements. The cutting elements may be formed from the same base material as is the cone (typically steel) and are known as "teeth". These bits are typically referred to as "milled tooth" bits. Other roller cone bits include "insert" cutting elements that are press (interference) fit into holes formed and/or machined into the roller cones. The inserts may be formed from, for example, tungsten carbide, natural or synthetic diamond, boron nitride, or any one or combination of hard or superhard materials.

[0005] Drag bits (or fixed cutter) are a type of rotary drill bits having no moving parts on them. One type of drag bit is known in the art as a PDC bit. PDC bits include a bit body with a plurality of blades extending radially therefrom. A plurality of cutting elements are secured on the blades. The cutting elements may be formed from any one or combination of hard or superhard materials, for example, natural or synthetic diamond, boron nitride, and tungsten carbide.

[0006] Most cutting elements include a substrate of tungsten carbide, a hard material, interspersed with a binder component, preferably cobalt, which binds the tungsten carbide particles together. When used in drilling earth formations, the primary contact between the tungsten carbide cutting element and the earth formation being drilled is the outer end of the cutting element. Tungsten carbide cutting elements tend to fail by excessive wear because of their softness. Thus, it is beneficial to offer this region of the cutting element greater wear protection.

[0007] An outer wear layer or crown that includes diamond particles, such as a polycrystalline diamond, can provide such improved wear resistance, as compared to the softer tungsten carbide component. Such a polycrystalline diamond layer typically includes diamond particles held together by a metal matrix, which also often consists of cobalt. The attachment of the polycrystalline diamond layer to the tungsten carbide substrate may be accomplished by brazing.

[0008] Many different types of tungsten carbides are known based on their different chemical compositions and physical structure. Of the various types of tungsten carbide commonly used in drill bits, cemented tungsten carbide (also known as sintered tungsten carbide) is typically used in cutting elements for drill bits.

[0009] Cemented tungsten carbide refers to a material formed by mixing particles of tungsten carbide, typically monotungsten carbide, and particles of cobalt or other iron group metal, and sintering the mixture. In a typical process for making cemented tungsten carbide, small tungsten carbide particles, *e.g.*, 1-15 microns, and cobalt particles are vigorously mixed with a small amount of organic wax which serves as a temporary binder. An organic solvent may be used to promote uniform mixing. The mixture may be prepared for sintering by either of two techniques: it may be pressed into solid bodies often referred to as green compacts; alternatively, it may be formed into granules or particles such as by pressing through a screen, or tumbling and then screened to obtain more or less uniform particle size.

[0010] Such green compacts or particles are then heated in a vacuum furnace to first evaporate the wax and then to a temperature near the melting point of cobalt (or the like) to cause the tungsten carbide particles to be bonded together by the metallic phase. After sintering, the compacts are crushed and screened for the desired particle size. Similarly, the sintered particles, which tend to bond together during sintering, are gently churned in a ball mill with media to separate them without damaging the particles. Some particles may be crushed to break them apart. These are also screened to obtain a desired particle size. The crushed cemented carbide is generally more angular than the particles which tend to be rounded.

[0011] Cemented tungsten carbide is classified by grades based on the grain size of WC and the cobalt content and are primarily made in consideration of two factors that influence the lifetime of the tungsten carbide cutting structure; wear resistance and toughness. As a result, cutting elements known in the art are generally formed of cemented tungsten carbide with average grain sizes about less than 3 μm as measured by ASTM E-112 method, cobalt contents in the range of about 6-16% by weight, and hardness in the range of about 86 to 91 Ra.

[0012] For a WC/Co system, it is typically observed that the wear resistance increases as the grain size of tungsten carbide or the cobalt content decreases. On the other hand, the fracture toughness increases with larger grains of tungsten carbide and greater percentages of cobalt. Thus, fracture toughness and wear resistance (i.e., hardness) tend to be inversely related: as the grain size or the cobalt content is decreased to improve wear resistance of a specimen, its fracture toughness will decrease, and vice versa.

[0013] Due to this inverse relationship between fracture toughness and wear resistance, the grain size of tungsten carbide and cobalt content are selected to obtain desired wear resistance and toughness. For example, a higher cobalt content and larger WC grains are used when a higher toughness is required, whereas a lower cobalt content and smaller WC grain are used when a better wear resistance is desired. The relationship between toughness and wear for carbide composites having varying particle size and cobalt content is shown in FIG. 1.

[0014] During manufacture of the cutting elements, the materials are typically subjected to sintering under high pressures and high temperatures. These manufacturing conditions can lead to potential problems involving dissimilar elements being bonded to each other and the diffusion of various components, resulting in residual stresses induced on the composites. The residual stress induced composites can often result in insert breakage, fracture or delamination under drilling conditions.

[0015] Additionally, the combination of the high temperature and high pressure for the length of time necessary to form the cutting elements inherently result in grain growth and thus larger carbide grain sizes. For example, a powder starting with 50 nm WC grains prior to HTHP sintering may result in a composite having WC grains larger than 1 μm after sintering. Prior art methods require the addition of grain growth inhibitors, such as vanadium, chromium, or compounds including these elements, when a smaller grain size is desired. However, the use of grain growth inhibitors typically produces undesirable side effects by altering the physical characteristics of the sintered carbide product, especially when the carbide product is to be brazed to a diamond layer or crown.

[0016] Generally, because a decrease in WC particle size results in an increase in hardness, wear resistance and transverse rupture strength of the composites, composites having nanoparticles may be desirable. However, because of the tendency for grain growth during the formation of a composite, this results in a limitation on the ability to obtain nanoparticles. Accordingly, there exists a need for composites and methods of forming such composites that exhibit increased wear properties.

SUMMARY OF INVENTION

[0017] In one aspect, the present invention relates to a cutting element that includes a substrate formed from a carbide composite, where the carbide composite includes tungsten carbide particles, and a metallic binder, and where the tungsten carbide particles have a particle size ranging from 10 to 100 nm, and the carbide composite has a hardness greater than 85 Rockwell A

[0018] In another aspect, the present invention relates to a method for making a wear resistant element that includes the steps of providing a mixture of green carbide particles and a metallic binding material, and sintering the mixture with microwave energy to form a composite having a first carbide region and a second carbide region, wherein the first carbide region has an average particle size of less than about 100 nm and the second carbide region has an average particle size ranging from about 3 to about 10 μm.

[0019] In yet another aspect, the present invention relates to a carbide composite that includes a first carbide having an average particle size of less than about 100 nm, a second carbide having an average particle size ranging from about 3 to about 10 μm, and a metallic binder disposed around the carbide particles.

[0020] In yet another aspect, the present invention relates to a carbide composite that includes a first carbide region, a second carbide region, and a metallic binder phase disposed around carbide particles of the first and second carbide regions, wherein the first carbide region has an average particle size less than an average particle size of the second carbide region, and wherein the composite is formed by a rapid consolidation process

[0021] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0022] FIG. 1 shows a graphical comparison of fracture toughness vs. wear number for conventional carbides.

[0023] FIG. 2 shows a graphical comparison of fracture toughness vs. wear number for convention carbides and carbides in accordance with embodiments of the present invention.

[0024] FIG. 3 is a carbide composite made in accordance with one embodiment of the present invention.

[0025] FIG. 4 is a SEM mircograph of a carbide composite made in accordance with one embodiment of the present invention.

[0026] FIGS 5, 5A, and 5B show a roller cone drill bit and corresponding cutting element made in accordance with one embodiment of the present invention.

[0027] FIGS. 6 and 6A show a fixed cutter drill bit and corresponding cutting element made in accordance with one embodiment of the present invention.

[0028] FIG. 7 shows a cutting element made in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

[0029] In one aspect, embodiments of the invention relate to wear resistant elements and carbide composites having nano-scale carbide particles. In another aspect, embodiments of the invention relate to microwave sintered composites. Microwave sintering may provide for a process of forming a hard composite. As compared to a conventional high temperature, high pressure (HTHP) sintering process, such as that disclosed in U.S. Patent Nos. 4,694,918; 5,370,195; and 4,525,178, sintering using microwave energy may reduce the pressures used, decrease the applied temperature, and reduce the sintering time. The microwave sintering process may be applied to a number of composite materials and may thus form composites having greater wear resistant properties. Tungsten carbide, polycrystalline diamond, thermally stable polycrystalline diamond, silicon carbide, etc, are among the materials suitable for microwave sintering.

[0030] In one embodiment, a microwave sintered composite made in accordance with the present invention is a carbide composite having a carbide particle size on the "nano-scale." As described above, as the grain size of metal carbides decreases, the wear resistance of the carbide composite may increase. However, typical processes involved in the formation of carbide composite present a limitation on the ability to achieve nano grain carbide particle sizes. As shown in FIG. 2, carbide composites having nano grain carbide particles may allow for improved wear properties, as compared to conventional carbides.

[0031] Carbide composites having nano grain carbide particles may include carbide particles having a particle size less than 100 nanometers. These small carbide particles may be referred to as "nano grain" particles or "nanoparticles". In one embodiment, a carbide composites may be comprised of from about 10 to 100 percent carbide particles having a particle size less than 100 nanometers. In another embodiment, the carbide composite may further include at least one of a coarse grain carbide and a fine grain carbide. As used herein, a coarse grain carbide is a carbide having an average carbide particle size between 3 and 10 microns, and a fine grain carbide is a carbide having an average carbide particle size between 0.5 and 4 microns. The combination of nano grain and coarse and/or fine grain carbide may allow for a uniform, gradual, or step distribution of the carbide particles in the formed composite. A composite that includes nano grain particles and coarse grain particles may be formed by microwave sintering, or other rapid consolidation processes that include plasma assisted sintering, pressure assisted sintering, explosive compaction, high frequency induction heating and rapid omnidirectional compaction. Referring to FIG. 3, a carbide composite according to one embodiment of the present invention is shown. The carbide composite 30 may include a mixture of coarse grain carbide particles 32 and nano grain particles 34, where a core of coarse grain particles 32 are surrounded by a layer of nano grain particles 34.

[0032] A carbide composite having carbide particles that having a particle size less than 100 nm may be used to form a substrate of a cutting element that may be used in drill bit. In one embodiment, a cutting element that includes carbide particles having a particle size less than 100 nm may have a hardness greater than 85 Rockwell A. In other embodiments, the hardness of such composite may be greater than 87, 89, or 91 Rockwell A. The carbide particles having a particle size of less than 100 nanometers may comprise from about 10 to 100 percent of the tungsten carbide present in the substrate. The remaining tungsten carbide may have particle sizes greater than 100 nm, including, but not limited to, carbides with particle sizes in the range of .5 to 4 μm and 3 to 10 μm.

[0033] In one embodiment of the invention, the carbide composite may include a metal carbide, such as tungsten carbide. Additionally, the carbide composite may be a sintered tungsten carbide composite. It is well known that various metal carbide compositions may be used in addition to tungsten carbide; such suitable materials include, for example, tantalum carbide or titanium carbide. Further, references to the use of tungsten carbide are for illustrative purposes only, and no limitation on the type of carbide used is intended.

[0034] Within the carbide composite, the metal carbide grains may be supported within a matrix of a metallic binder. In some embodiments of the present invention, the metallic binder may be selected from cobalt, nickel, iron, metal alloys, and mixtures thereof, preferably cobalt. In other embodiments, the carbide composite includes from about 10 to about 40 weight percent metallic binder. In yet other embodiments, the metallic binder may be selected from cobalt, nickel, iron, titanium, tantalum, chromium, vanadium, metal alloys, and mixtures thereof.

[0035] In another embodiment, a microwave sintered composite may include a first region and a second region, where the first region has an average particle size less than an average particle size of the second region. In the composite, the carbide particles of the first region may surround individual carbide particles of the second region. The carbide particles from the first region may be uniformly distributed in the matrix of binder materials. Referring to FIG. 4, a SEM micrograph of a carbide composite made in accordance with the present invention is shown. Additionally, the amount of nano grain carbide particles present in some embodiments of the present invention may range from 10 to 50 weight percent of the binder material.

[0036] In some embodiments, the first region may include carbide particles having an average carbide particle size less than 100 nm and the second region may include carbide particles having an average particle size between 3 and 10 μm. In other embodiments, the first region or second regions may include carbide particles having an average carbide particle size from 0.5 to 4 μm.

[0037] Additionally, the composite may include a third carbide region having a third average particle size, as well as fourth and fifth carbide regions having fourth and fifth average particle sizes. Carbide composites having multimodal particle size distribution may packed in various packing structures depending on the distribution as known by one having ordinary skill in the art.

[0038] In one embodiment, the multiple regions may be formed simultaneously. In another embodiment, the multiple regions of such microwave sintered composite may be formed as a step function. Such step function may allow for a composite having a uniform consistency to be formed, and then additional regions be sequentially added to the composite to form a composite having multiple regions.

[0039] According to some embodiments, the carbide composite formed by microwave sintering may include multiple regions, each having a different material composition.

A first region may constitute an outer surface of the carbide composite and the second region may constitute a body. In one embodiment, a first region may have an average carbide particle size less than an average carbide particle size of a second region. In some embodiments, the average carbide particle size may gradually change from the first region to the second region. However, in other embodiments, the first region and the second region are discrete layers within the composite. In addition to the first and second regions, the carbide composite may further include a third region disposed between the first region and second region, where the third region has an average carbide particle size greater than the first region and less than the second region. In the microwave sintered carbide having multiple regions, the first, second, and third carbide regions may each be selected from average carbide particles sizes of less than 100 nanometers, from 0.5 to 4 μm, and from 3 to 10 μm.

[0040] However, the scope of the present invention is not solely limited to the formation of carbide composite having nano grain carbides. Rather it is intended to be within the scope of the present invention that additional wear resistant materials may be microwave sintered to form wear resistant elements.

[0041] Wear resistant materials according to embodiments of the present invention may include polycrystalline diamond, thermally stable polycrystalline diamond, cubic boron nitride, silicon, silicon carbide, cermets, other metal carbides, and composites thereof. These wear resistant materials may be formed by microwave sintering, and may additionally be used in conjunction with a carbide composite having nano grain carbides. For example, a cutting element according to the present invention may include a carbide composite having a nano grain carbide and a layer of a wear resistant material selected from microwave sintered polycrystalline diamond, thermally stable polycrystalline diamond, cubic boron nitride, silicon, silicon carbide, cermets, other metal carbides, and composites thereof.

[0042] A polycrystalline diamond layer may be formed from a composite including diamond crystals and a metal catalyst, such as cobalt. Alternatively, the polycrystalline diamond layer may be formed from a composite including diamond crystals, cobalt, and particles of carbides or carbonitrides of the transition metals selected from the group consisting of W, Ti, Ta, Cr, Mo, Cb, V, Hf, Zr, and mixtures thereof. A polycrystalline diamond layer includes individual diamond "crystals" that are interconnected. The individual diamond crystals thus form a lattice structure. A metal catalyst, such as cobalt, may be used to promote recrystallization of the diamond particles and formation of the lattice structure. Thus, cobalt particles are typically found in the interstitial spaces in the diamond lattice structure.

[0043] Thermally stable polycrystalline diamond (TSP) may also be used as a wear resistant material in a cutting element according to embodiments of the present invention. The manufacture of TSP is known in the art, but a brief description of one process is described herein. As mentioned, when formed, a polycrystalline diamond layer comprises a diamond lattice structure with cobalt particles often being found within the interstitial spaces in the diamond lattice structure. Cobalt has a significantly different coefficient of thermal expansion, as compared to diamond, so upon heating of the diamond layer, the cobalt will expand, causing cracks to form in the lattice structure, resulting in deterioration of the diamond layer.

[0044] In order to obviate this problem, strong acids may be used to "leach" the cobalt from the diamond lattice structure. Removing the cobalt causes the diamond layer to become more heat resistant, but also causes the diamond layer to become more brittle. Accordingly, in certain cases, only a select portion (measured in either depth or width) of a diamond layer is leached, in order to gain thermal stability without losing impact resistance. As used herein, the term TSP includes both of the above (*i.e.*, partially and completely leached) compounds.

[0045] Alternatively, TSP may be formed by forming the diamond layer in a press using a binder other than cobalt, one such as silicon, which has a coefficient of thermal expansion more similar to that of diamond than cobalt has. During the manufacturing process, a large portion, 80 to 100 volume percent, of the silicon reacts with the diamond lattice to form silicon carbide which also has a thermal expansion similar to diamond. Upon heating, any remaining silicon, silicon carbide, and the diamond lattice will expand at more similar rates as compared to rates of expansion for cobalt and diamond, resulting in a more thermally stable layer.

[0046] Cubic boron nitride (CBN) refers to an internal crystal structure of boron atoms and nitrogen atoms in which the equivalent lattice points are at the corner of each cell. Boron nitride particles typically have a diameter of approximately one micron and appear as a white powder. Boron nitride, when initially formed, has a generally graphite-like, hexagonal plate structure. When compressed at high pressures (such as 10^6 psi) cubic boron nitride particles will be formed with a hardness very similar to diamonds. Accordingly, cubic boron nitride may be used as a wear resistant material to overlay at least a portion of a carbide composite in cutting elements according to the present invention.

[0047] In some embodiments, the wear resistant material may include cubic boron nitride having an average grain size of about 1.5 μm, where the cubic boron nitride comprised about 50 volume percent of the wear resistant material. In other embodiments, the wear resistant material may include cubic boron nitride having an average grain size of about 2.5 μm, where the cubic boron nitride comprised about 60 volume percent of the wear resistant material. The wear resistant material may also comprise a ceramic or cermet material.

[0048] In yet other embodiments, the wear resistant material may include a composite of diamond and silicon, silicon carbide, or other desirable materials. The wear resistant composite may include either polycrystalline diamond or thermally stable polycrystalline diamond.

[0049] In some embodiments, microwave sintered composites may be used in cutting elements for drill bits. In one embodiment, carbide composites having carbide particles ranging less than 100 nanometers and a metallic binder surrounding the carbide particles may be included in a cutting element. In another embodiment, microwave sintered composites including a sintered carbide may be included in a cutting element. The cutting elements of the present invention may be used in various types of drill bits, including roller cone "insert" bits and fixed cutter "PDC" bits.

[0050] Referring to FIG. 5 and 5A, a roller cone "insert" bit 500 having cutting elements according to the present invention is shown. The bit 500 has a body 504 with legs 506 extending generally downward, and a threaded pin end 508 opposite thereto for attachment to a drill string (not shown). Journal shafts (not shown) are cantilevered from legs 506. Rolling cutters (or roller cones) 512 are rotatably mounted on journal shafts (not shown). Each roller cone 512 has a plurality of cutting elements 520 mounted thereon. As the roller cone 512 rotates, individual cutting elements 520 are rotated into contact with the formation and then out of contact with the formation. In one embodiment, cutting element 520 may include a carbide composite made in accordance with the present invention. In another embodiment, cutting element 520 may include a wear resistant element made in accordance with the present invention

[0051] Referring to FIG. 6 and 6A, a fixed cutter bit and cutting element according to the present invention is shown. The drag bit 600 has a bit body 602 with a plurality of blades 604 extending from the central longitudinal axis of rotation 606 of the drill bit 600. A plurality of cutting elements 610 are secured on the blades. Cutting elements 610 may include a substrate 612 and a wear resistant cutting portion 614 disposed on the substrate 612. In one embodiment, substrate 612 may include a carbide composite made in accordance with the present invention. In another embodiment, the wear resistant cutting portion 614 may include a sintered composite, such as microwave sintered polycrystalline diamond made in accordance with the present invention.

[0052] In some embodiments, the cutting element may include a carbide composite that has carbide particles having a particle size of less than about 100 nanometers, a metal binder, and a wear resistant material overlaying at least a portion of the carbide composite. As shown in FIG. 5B, a protective coating 522 may be applied to a surface 524 of a cutting element 520 to, for example, reduce wear. The protective coating 522 may comprise, for example, a polycrystalline diamond layer to overlay over a base cutting element material 526 that comprises a carbide composite that includes carbide particles having a particle size of less than 100 nanometers.

[0053] Referring to FIG. 7, a cutting element having multiple carbide regions according to other embodiments of the present invention is shown. Cutting element 700 may include a first region 702 as the wear surface of the cutting element 700 and a second region 704 that is the body of the cutting element 700. Additionally, a third region 706 may be disposed between the first region 702 and the second region 704. Each region of the cutting element may include a differing carbide composition such that a functionally graded cutting element is produced.

[0054] Sintering Process

[0055] The sintering process may involve a microwave energy process. Examples of microwave sintering processes can be found, for example, in U.S. Patent No. 5,848,348; 6,126,895; and 6,011,248, which are herein incorporated by reference in their entirety. The carbide composite and the wear resistant materials may be formed by the application of heat, such as by sintering of "green" particles to create intercrystalline bonding between the particles. Briefly, to form a sintered composite, an unsintered mass of particles is placed within an enclosure of the reaction cell. If forming a carbide composite or polycrystalline diamond, for example, a metal catalyst, such as cobalt, may be included with the unsintered mass of carbide particles. The reaction cell is then placed under processing conditions sufficient to cause the bonding between the carbide particles and binding material. Suitable processing conditions may include a temperature ranging from 1200 to 1350°C for 8-20 minutes, with a total cycle time of less than 2 hours. Application of the sintering processing will cause metal carbide particles to sinter and form a carbide composite. The sintering process may also cause diamond crystals, or other superhard materials, to sinter and form a polycrystalline diamond layer. Similarly, application of sintering process may cause the diamond crystals and carbide particles to sinter such that they are no longer in the form of discrete particles that can be separated from each other. Further, all of the layers may sinter to each other.

[0056] In other embodiments, other rapid consolidation processes that may be used to form composites of the present invention include plasma assisted sintering, pressure assisted sintering, explosive compaction, high frequency induction heating and rapid omnidirectional compaction.

[0057] The composites according to various embodiments of the present invention may be used in a variety of applications including, cutting elements for drill bits for drilling earth formations, tooling blanks, woodworking tools, wear surfaces for a variety of cutting tools, etc. It should be understood that the abovementioned applications only serve as an example of the variety of applications that can use the carbide composites of the present invention.

[0058] As compared to a conventional sintering process, microwave sintering and other rapid sintering processes can use lower sintering temperatures, sintering time, and total cycle time to achieve a composite having a greater density, hardness, and bending strength, and lower average grain size.

[0059] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

CLAIMS

What is claimed:

1. A cutting element comprising:
   a substrate formed from a carbide composite, the carbide composite comprising:
   tungsten carbide particles; and
   a metallic binder,
   wherein the tungsten carbide particles have a particle size ranging from 10 to 100 nm, and wherein the carbide composite has a hardness greater than 85 Rockwell A.

2. The cutting element of claim 1, wherein the tungsten carbide particles having a particle size ranging from 10 to 100 nm comprise from about 10 to 100 percent of the tungsten carbide particles.

3. A method for making a wear resistant element, comprising:
   providing a mixture of green carbide particles and a metallic binding material; and
   sintering the mixture with microwave energy to form a composite having a first carbide region and a second carbide region, wherein the first carbide region has an average particle size of less than about 100 nm and the second carbide region has an average particle size ranging from about 3 to about 10 μm.

4. A carbide composite, comprising:
   a first carbide having an average particle size of less than about 100 nm;
   a second carbide having an average particle size ranging from about 3 to about 10 μm; and
   a metallic binder disposed around the carbide particles.

5. The carbide composite of claim 3, wherein the composite is formed by a process selected from microwave sintering, plasma assisted sintering, pressure assisted sintering, explosive compaction, and rapid omnidirectional compaction.

6. The carbide composite of claim 3, wherein the metallic binder is selected from cobalt, nickel, iron, and alloys thereof.

7. The carbide composite of claim 3, wherein the carbide composite comprises from about 10 to about 40 weight percent metallic binder.

8. The carbide composite of claim 3, wherein the carbide composite has a hardness greater than about 85 Rockwell A.

9. The carbide composite of claim 3, wherein the first carbide is in an amount ranging from 10 to 50 percent of the metallic binder.

10. The method of claim 3, wherein carbide particles of the second carbide region are surrounded by carbide particles of the first carbide region.

11. The method of claim 3, wherein the carbide particles of the first carbide region are uniformly distributed in the metallic binder phase.

12. A carbide composite, comprising:
a first carbide region;
a second carbide region; and
a metallic binder phase disposed around carbide particles of the first and second carbide regions, wherein the first carbide region has an average particle size less than an average particle size of the second carbide region, and wherein the composite is formed by a rapid consolidation process.

13. The carbide composite of claim 12, wherein the composite is formed by a microwave sintering process.

14. The carbide composite of claim 12, wherein the metallic binder is selected from cobalt, nickel, iron, and alloys thereof.

15. The carbide composite of claim 12, wherein the carbide composite comprises from about 10 to about 40 weight percent metallic binder.

16. The carbide composite of claim 12, wherein each carbide particle of the second carbide region is surrounded by carbide particles of the first carbide region.

17. The carbide composite of claim 12, wherein the carbide particles of the first carbide region are uniformly distributed in the metallic binder phase.

18. The carbide composite of claim 12, wherein the first carbide region comprises carbide particles having an average carbide particle size less than 100 nm and the second carbide region comprises carbide particles having an average carbide particle size from 3 to 10 μm.

19. The carbide composite of claim 12, wherein the first carbide region is in an amount ranging from 10 to 50 percent of the metallic binder.

20. The carbide composite of claim 12, further comprising a third carbide region having a third average particle size.

Application number / numéro de demande: 2568672

Figures:

Pages: 3, 4, 5B, 6, 7, 1, 2, 5

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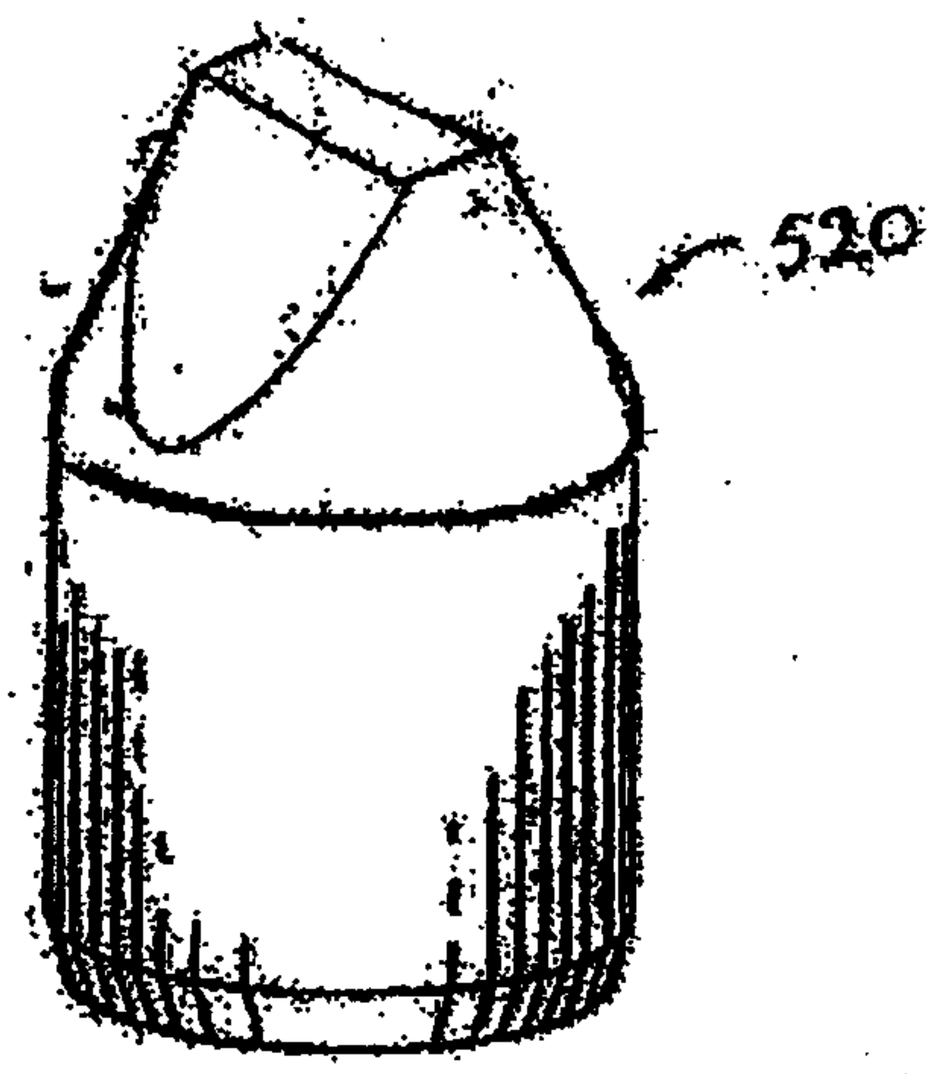

FIG. 5A

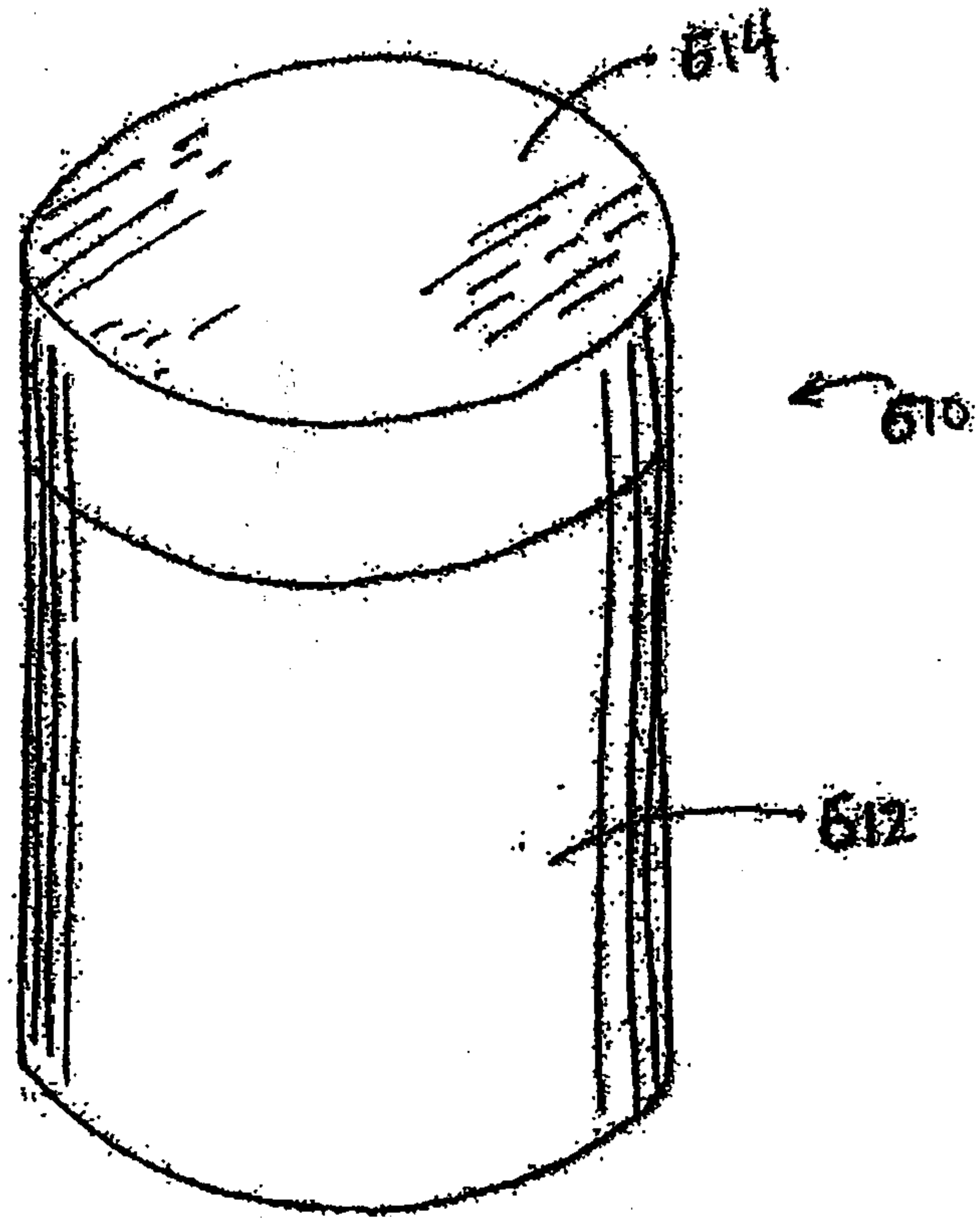

Fig. 6A