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(54) **THERMALLY STABLE POLYCRYSTALLINE
ULTRAHARD MATERIAL REINFORCED
WITH FIBROUS MATERIALS**

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(57) **ABSTRACT**

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29, 2011.

A polycrystalline diamond construction includes a diamond body having a thermally stable diamond matrix comprising bonded-together diamond crystals, wherein the diamond matrix includes a diamond volume content of at least 99%, and a plurality of fibers extending through the thermally stable diamond matrix. The diamond construction may be bonded to a substrate forming a shear cutter. The shear cutter may be mounted on a bit body.

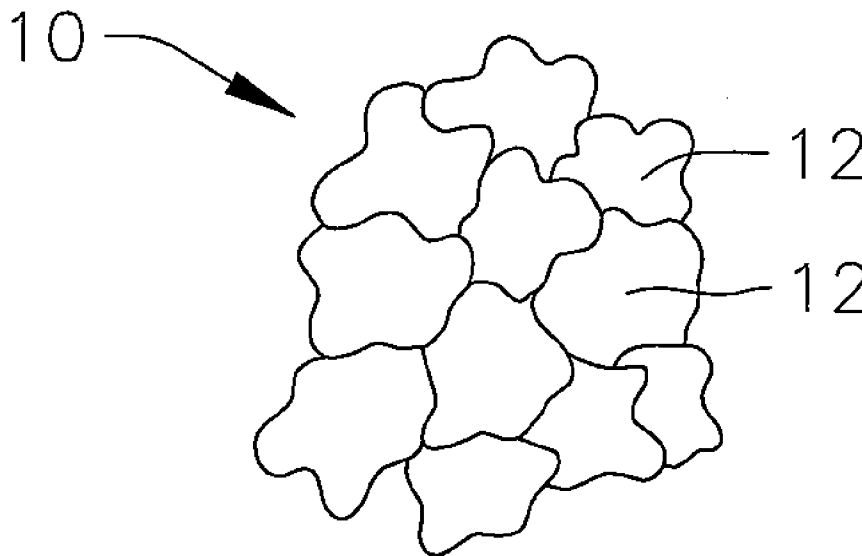


FIG. 1

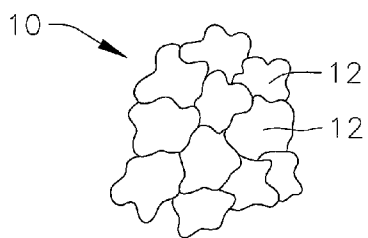


FIG. 2

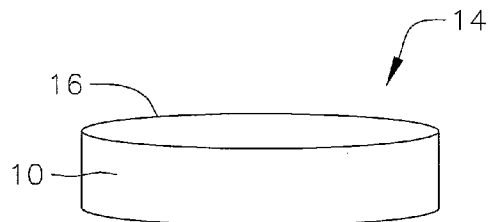


FIG. 3

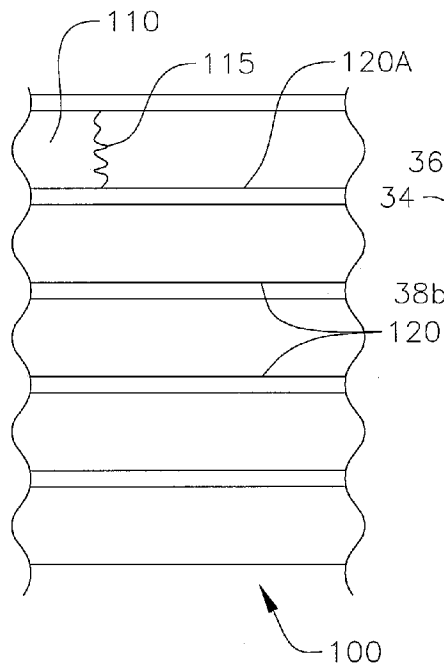


FIG. 5

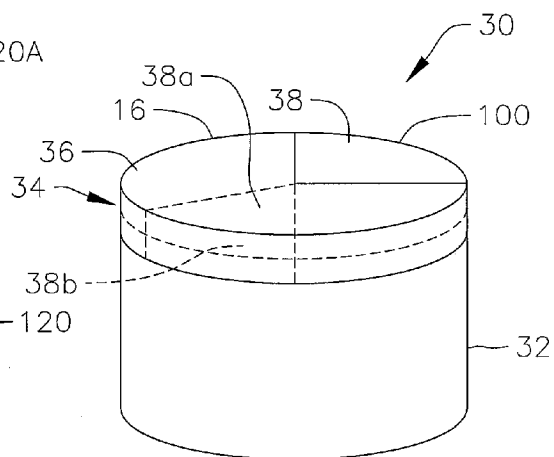


FIG. 4

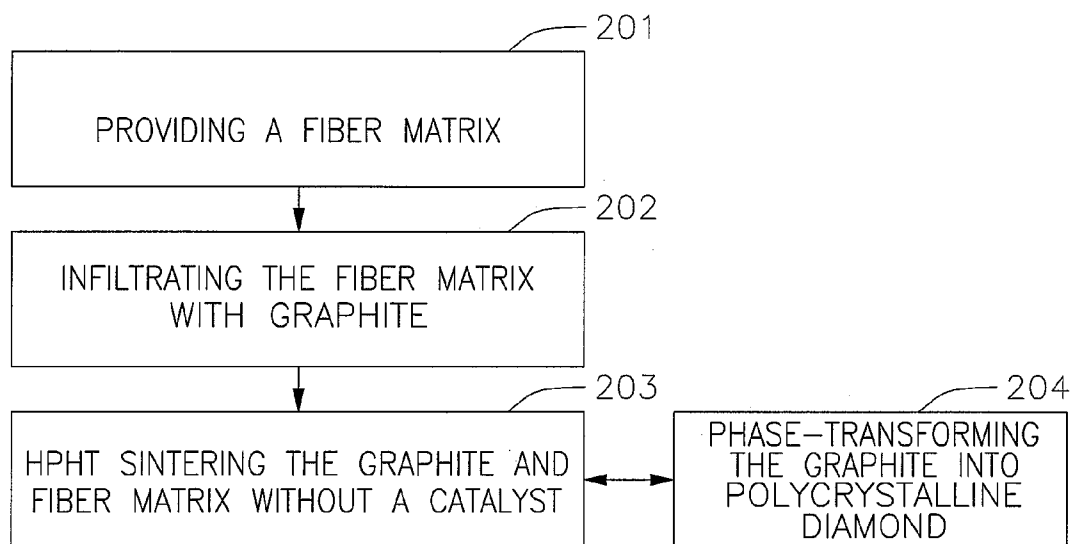


FIG. 8

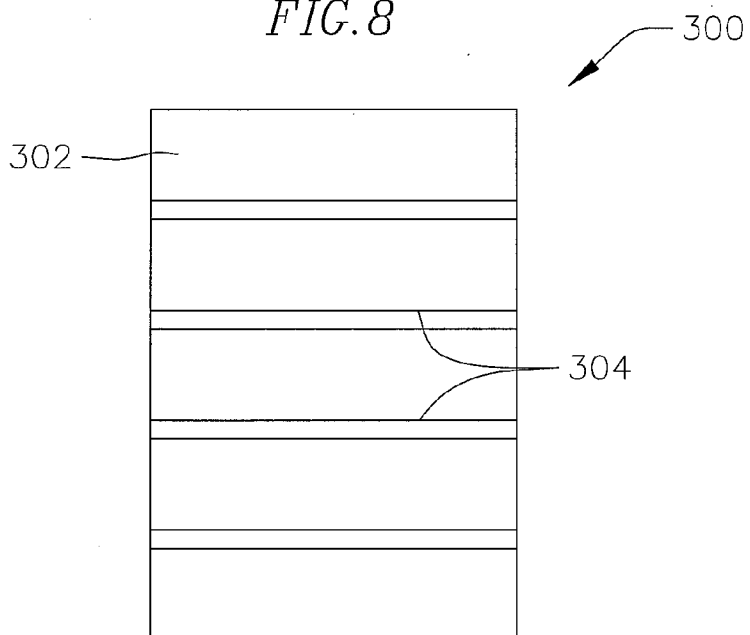


FIG. 6

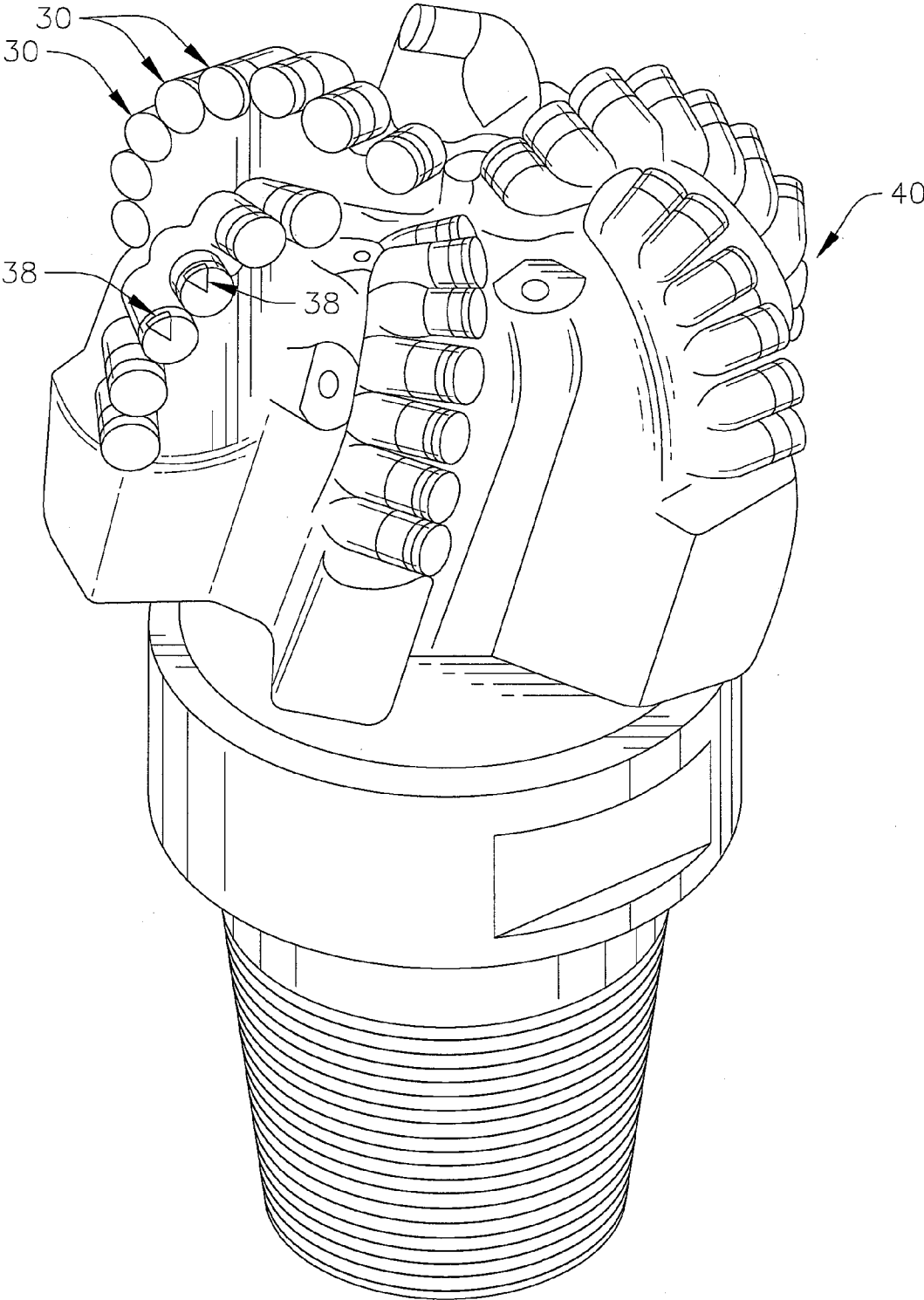


FIG. 7a

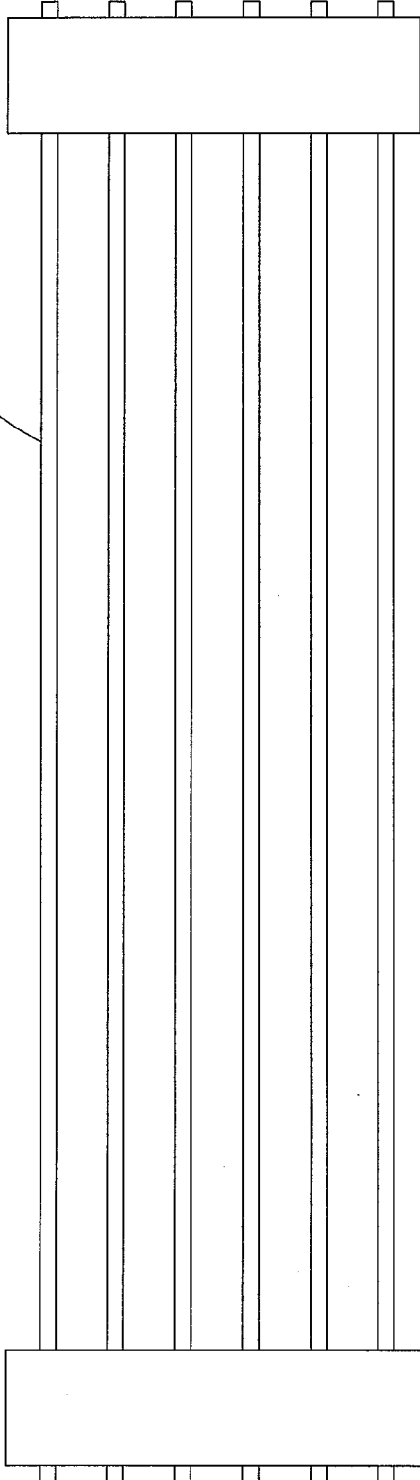
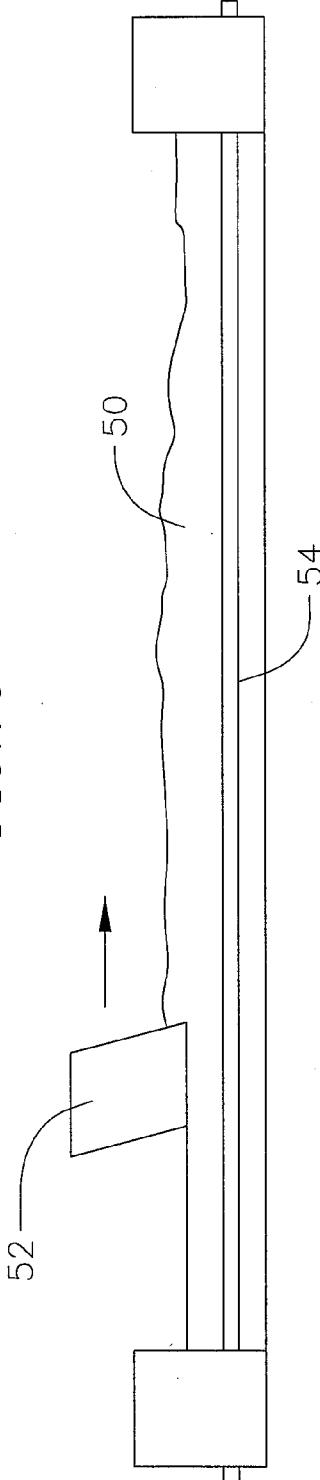


FIG. 7b



**THERMALLY STABLE POLYCRYSTALLINE
ULTRAHARD MATERIAL REINFORCED
WITH FIBROUS MATERIALS**

CROSS-REFERENCE TO RELATED INVENTION

[0001] This application claims the benefit of a related U.S. Provisional Application Ser. No. 61/581,419, filed on Dec. 29, 2011, entitled "Thermally Stable Polycrystalline Ultra-hard Material Reinforced with Fibrous Materials," to J. Daniel Belnap, the disclosure of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] The present invention relates to thermally stable ultra-hard materials, and more particularly to thermally stable polycrystalline ultra-hard materials reinforced with fibrous materials for improved toughness, and to methods for forming the same. Polycrystalline diamond material is known for its good wear resistance and hardness, and is often used in cutting tools and rock drilling tools. To form polycrystalline diamond, diamond particles are sintered at high pressure and high temperature (HPHT sintering) to produce an ultra-hard polycrystalline structure. A catalyst material such as cobalt or another metal is added to the diamond particle mixture prior to sintering and/or infiltrates the diamond particle mixture during sintering in order to promote the intergrowth of the diamond crystals during HPHT sintering, to form the polycrystalline diamond (PCD) structure. Metals conventionally employed as the catalyst are selected from the group of solvent metal catalysts selected from Group VIII of the Periodic table, including cobalt, iron, and nickel, and combinations and alloys thereof. After HPHT sintering, the resulting PCD structure includes a network of interconnected diamond crystals or grains bonded to each other, with the catalyst material occupying the interstitial spaces or pores between the bonded diamond crystals. The diamond particle mixture may be HPHT sintered in the presence of a substrate, to form a PCD compact bonded to the substrate. The substrate may also act as a source of the metal catalyst that infiltrates into the diamond particle mixture during sintering.

[0003] The amount of catalyst material used to form the PCD body represents a compromise between desired properties of strength, toughness, and impact resistance versus hardness, wear resistance, and thermal stability. While a higher metal catalyst content generally increases the strength, toughness, and impact resistance of the resulting PCD body, this higher metal catalyst content also decreases the hardness and wear resistance as well as the thermal stability of the PCD body. This trade-off makes it difficult to provide PCD having desired levels of hardness, wear resistance, thermal stability, strength, impact resistance, and toughness to meet the service demands of particular applications, such as in cutting and/or wear elements used in subterranean drilling devices.

[0004] Thermal stability can be particularly relevant during wear or cutting operations. Conventional PCD bodies may be vulnerable to thermal degradation when exposed to elevated temperatures during cutting and/or wear applications. This vulnerability results from the differential that exists between the thermal expansion characteristics of the solvent metal catalyst disposed interstitially within the PCD body and the thermal expansion characteristics of the intercrystalline bonded diamond. This differential thermal expansion is known to start at temperatures as low as 400° C., and can

induce thermal stresses that are detrimental to the intercrystalline bonding of diamond and that eventually result in the formation of cracks that can make the PCD structure vulnerable to failure. Accordingly, such behavior is not desirable.

[0005] Another form of thermal degradation known to exist with conventional PCD materials is one that is also related to the presence of the solvent metal catalyst in the interstitial regions of the PCD body and the adherence of the solvent metal catalyst to the diamond crystals. Specifically, the solvent metal catalyst is known to cause an undesired catalyzed phase transformation in diamond (converting it to carbon monoxide, carbon dioxide, or graphite) with increasing temperature, thereby limiting the temperatures at which the PCD body may be used.

[0006] To improve the thermal stability of the PCD material, the catalyst material may be removed from the PCD body after sintering. This thermally stable PCD material (sometimes referred to as TSP) is formed by first HPHT sintering diamond particles in the presence of a solvent metal catalyst, to form a PCD body with the catalyst occupying the interstitial regions between the diamond crystals. Then, the catalyst material is removed from the PCD body, leaving a network of empty interstitial spaces between the diamond crystals. For example, one known approach is to remove a substantial portion of the catalyst material from at least a portion of the sintered PCD by subjecting the sintered PCD construction to a leaching process, which forms a thermally stable material portion substantially free of the catalyst material. If a substrate was used during the HPHT sintering, it is often removed prior to leaching.

[0007] In order to provide a more thermally stable ultra-hard diamond body, binderless polycrystalline diamond has been formed, without the use of a catalyst material, by converting graphite directly to diamond at ultra-high pressure and temperature. The resulting diamond material has a uniform intercrystalline diamond microstructure, without catalyst material interspersed between the diamond crystals. As a result, the binderless diamond body does not suffer from differential thermal expansion between diamond and catalyst.

[0008] However, while this binderless diamond body has high hardness and wear-resistance at elevated temperature, it is expected to exhibit a low fracture toughness, making the material brittle and susceptible to chipping, cracking, and fracturing during use.

[0009] Accordingly, there is still a need for a cutting element that incorporates a thermally stable ultra-hard diamond body, in order to provide toughness as well as wear resistance at elevated temperatures.

SUMMARY

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

[0011] The present disclosure relates to thermally stable ultra-hard materials, and more particularly to thermally stable polycrystalline ultra-hard materials reinforced with fibrous materials for improved toughness, and methods for forming the same. In one embodiment, a polycrystalline diamond construction includes a thermally stable diamond matrix, formed at ultra-high temperature and pressure without the use of a catalyst material. In one embodiment, the pressure is

between about 100-160 kbar, such as about 150 kbar, and the temperature is about 1800-2500° C. This thermally stable diamond matrix includes a network of diamond crystals bonded together and substantially devoid of interstitial spaces between the diamond crystals. Interspersed through this thermally stable diamond matrix is a network of fibers or fibrous materials that extend through the diamond matrix in desired or random orientations. These fibers are provided to reinforce the diamond matrix, providing increased toughness and ductility and preventing crack growth through the material. By preventing or slowing cracks from propagating across the diamond matrix, the fibers prevent early failure and allow the diamond construction to continue operating. In one embodiment, the fiber-reinforced thermally stable diamond matrix is incorporated into a cutting element such as a shear cutter. According to another embodiment, a method of forming a fiber-reinforced thermally stable diamond matrix is also provided.

[0012] In one embodiment, a polycrystalline diamond construction includes a diamond body with a thermally stable diamond matrix having bonded-together diamond crystals and a plurality of fibers extending through the thermally stable diamond matrix. The diamond matrix comprises a diamond volume content of at least 99%.

[0013] In one embodiment, a method of forming a fiber-reinforced thermally stable polycrystalline diamond construction includes providing a fiber matrix, infiltrating the fiber matrix with graphite, and HPHT sintering the graphite and the fiber matrix at ultra-high temperature and pressure, without a catalyst material.

[0014] In one embodiment, a polycrystalline diamond construction includes a diamond body with a diamond matrix having bonded-together diamond crystals and interstitial spaces between the diamond crystals, and a carbonate catalyst disposed within the interstitial spaces; and a plurality of fibers extending through the diamond matrix.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 illustrates a schematic of a material microstructure of a thermally stable diamond matrix according to an example embodiment.

[0016] FIG. 2 illustrates a perspective view of a diamond body incorporating the material microstructure of FIG. 1.

[0017] FIG. 3 illustrates a partial cross-sectional view of a thermally stable diamond matrix including fibrous materials, according to an example embodiment.

[0018] FIG. 4 illustrates a flowchart of a method of forming a thermally stable diamond matrix, according to an example embodiment.

[0019] FIG. 5 illustrates a perspective view of a cutting element incorporating a thermally stable diamond matrix, according to an example embodiment.

[0020] FIG. 6 illustrates a perspective view of a drag bit incorporating the cutting element of FIG. 5.

[0021] FIG. 7a illustrates a top view and FIG. 7b is a side view of a fiber preform.

[0022] FIG. 8 illustrates a partial cross-sectional view of a pre-sintered carbonate diamond powder with stacked fiber layers, according to an example embodiment.

DETAILED DESCRIPTION

[0023] The present disclosure relates to thermally stable ultra-hard materials, and more particularly to thermally stable

polycrystalline ultra-hard materials reinforced with fibrous materials for improved toughness, and methods for forming the same. In one embodiment, a polycrystalline diamond construction includes a thermally stable diamond matrix, formed at ultra-high temperature and pressure without the use of a catalyst material. In one embodiment, the pressure is between about 100-160 kbar, such as about 150 kbar, and the temperature is about 1800-2500° C. This thermally stable diamond matrix includes a network of diamond crystals bonded together and substantially devoid of interstitial spaces between the diamond crystals. Interspersed through this thermally stable diamond matrix is a network of fibers or fibrous materials that extend through the diamond matrix in desired or random orientations. These fibers are provided to reinforce the diamond matrix, providing increased toughness and ductility and preventing crack growth through the material. By preventing cracks from propagating across the diamond matrix, the fibers prevent early failure and allow the diamond construction to continue operating. In one embodiment, the fiber-reinforced thermally stable diamond matrix is incorporated into a cutting element such as a shear cutter. According to another embodiment, a method of forming a fiber-reinforced thermally stable diamond matrix is also provided.

[0024] For clarity, as used herein, the term “PCD” refers to conventional polycrystalline diamond that has been formed with the use of a metal solvent catalyst during an HPHT sintering process, forming a microstructure of bonded diamond crystals with the catalyst material occupying the interstitial spaces or pores between the bonded diamond crystals. “Thermally stable PCD” (or TSP) refers to PCD material which has been subsequently treated to substantially remove the catalyst material from at least a portion of the PCD body, such as by leaching all or part of the PCD body after HPHT sintering, to remove the catalyst material from the interstitial regions of the PCD body. As described further below, embodiments herein provide a “thermally stable diamond matrix” that is formed without the use of a metal catalyst. This diamond material is referred to as “thermally stable diamond matrix” and not as PCD, in order to clarify that it does not utilize a metal solvent catalyst, and to distinguish it from thermally stable PCD (TSP) which is formed by HPHT sintering with a catalyst and then removing the catalyst after sintering. Though not formed with a catalyst, the thermally stable diamond matrix has a polycrystalline microstructure, as described in more detail below.

[0025] As described below, embodiments herein provide a thermally stable diamond matrix through a process that does not utilize a metal catalyst material. This thermally stable diamond material may also be referred to as a “binderless” diamond material. A region of a thermally stable diamond matrix 10 is schematically illustrated in FIG. 1, according to an embodiment of the present disclosure. The thermally stable diamond matrix 10 has a polycrystalline microstructure including multiple diamond grains or crystals 12 bonded to each other. As shown in FIG. 1, this material microstructure is substantially devoid of gaps or interstitial spaces between the diamond crystals 12. The diamond crystals 12 are bonded directly to each other. The thermally stable diamond matrix 10 is essentially pure carbon, with a diamond volume fraction of substantially 100%. There is no binder phase or catalyst material between the diamond crystals 12. This material is described as “substantially” devoid of gaps and interstitial spaces, and “substantially” 100% diamond, in order to allow for the possibility of small imperfections and deviations

within the diamond matrix **10** which may leave small gaps or spaces between some of the diamond crystals. In one embodiment the material microstructure of the thermally stable diamond matrix has a diamond volume content of at least 99%, and in another embodiment at least or about 99.5%, and in another embodiment at least or about 99.8%, and in another embodiment at least or about 99.9%. In one embodiment this diamond matrix **10** has a fine diamond grain size, such as an average diamond grain size of about 50 nm or less.

[0026] This diamond matrix **10** is inherently thermally stable, due to its uniform diamond content. There is no differential thermal expansion between different phases of the material. As a result, diamond bodies formed from this thermally stable diamond matrix **10** can exhibit very high strength even at elevated temperatures, where conventional PCD suffers from thermal degradation due to the differential expansion of the diamond and catalyst phases.

[0027] A polycrystalline diamond construction in the form of a cylindrical diamond body **14** is shown in FIG. 2. The diamond body **14** is formed from the thermally stable diamond matrix **10** of FIG. 1. The diamond body **14** includes a cutting edge **16** that is made up of this high-strength, thermally stable diamond matrix **10**.

[0028] A diamond body made up entirely of the material represented in FIG. 1 should provide high strength and wear resistance, but is also expected to suffer from reduced fracture toughness, due to the uniform composition of the material at substantially 100% diamond volume content. The reduction in fracture toughness is due in part to the fine grain size of the diamond matrix, as diamond materials with very fine grain sizes are known to exhibit a reduced fracture toughness, such as around 3 to around 5 MPa $\sqrt{\text{m}}$ ("MPa root meters") in fracture toughness testing. The result is a brittle material that is vulnerable to chipping, cracking, and fracturing.

[0029] Accordingly, according to an embodiment of the present disclosure, a thermally stable diamond matrix is reinforced with fibrous materials. A cross-sectional view of a fiber-reinforced thermally stable diamond construction **100** is shown in FIG. 3. The diamond construction **100** includes a thermally stable diamond matrix **110**, which is interspersed with fibers **120**. The thermally stable diamond matrix **110** includes diamond crystals bonded directly together, with the material microstructure shown in FIG. 1. This diamond matrix **110** is formed without the use of a catalyst material, and a method for forming this material is described further below. As shown in FIG. 3, one or more fibers **120** extend through the diamond matrix **110**, passing across the diamond construction **100** between the bonded diamond crystals.

[0030] This fiber-reinforced thermally stable diamond construction **100** is expected to exhibit improved qualities of toughness and impact resistance due to the presence of the fibers **120**. This results in increased toughness and ductility in the diamond construction **100**. For example, as shown in FIG. 3, during operation, a crack **115** may form in the ultra-hard diamond matrix **110**, and this crack may propagate across the diamond matrix **110**, separating the bonded diamond crystals. Without any fiber reinforcement, this crack may grow until it spans across the diamond construction, breaking apart the diamond matrix. For example, if such a diamond construction (without any fiber reinforcement) is incorporated into a diamond body on a cutting element, such as a shear cutter, the crack growth across the diamond body may cause early failure of the cutting element.

[0031] However, the fibers **120** counteract this failure mode by interrupting the growth of the crack across the diamond matrix **110**. As shown in FIG. 3, the crack **115** extends from an edge of the diamond construction **100** until it reaches the fiber **120A**. This fiber prevents (or hinders) the crack **115** from extending further through the material. The fiber has more ductility, and a longer strain to failure than the diamond, meaning that it can stretch and deform more than the diamond can without cracking. The fiber can withstand physical displacement by deforming, and thus can absorb the stress applied by the crack. In the diamond matrix, the crack applies a load on the diamond matrix at the tip of the crack, until the diamond matrix gives way and the crack grows further, releasing the load on the newly cracked region and applying a new load at the new crack tip. Once the crack reaches the fiber **120A**, the fiber **120A** absorbs this load applied at the tip of the crack, without unloading and extending the crack. As a result, the crack growth is slowed at the fiber **120A** and may not grow any further. Thus, the fiber **120 A** helps inhibit further crack growth. This behavior may take place not only at fiber **120A** but at all of the fibers **120** throughout the diamond construction **100**. Moreover, due to their strength and ductility, the fibers are capable of bridging across the cracked diamond matrix material and thereby provide structural support to the cracked body, which enables the diamond construction to have an increased service life.

[0032] The fiber-reinforced thermally stable diamond construction **100** shown in FIG. 3 includes fibers **120** extending in one direction across the diamond matrix **110**. This is shown for clarity and as an example. In other embodiment, the fibers **120** extend in multiple directions across the diamond matrix, such as a grid (with fibers oriented at 90 degrees relative to each other) or a more complex weave (with fibers oriented at various angles relative to each other). The fibers **120** may be oriented in the three spatial dimensions. The orientation of the fibers can be pre-determined and chosen according to the desired application and the anticipated stresses to the material. In one embodiment, the fibers are randomly oriented.

[0033] According to an embodiment, a method of forming a fiber-reinforced thermally stable diamond construction is provided, and is illustrated in FIG. 4. The method includes providing a fiber matrix (block **201**), infiltrating the fiber matrix with graphite (block **202**), and then HPHT sintering the graphite and fiber matrix at ultra-high temperature and pressure, without a catalyst material (block **203**). In one embodiment, the pressure is between about 100-160 kbar, such as about 150 kbar, and the temperature is about 1800-2500° C. HPHT sintering includes phase-transforming the graphite into polycrystalline diamond (block **204**). The result is a thermally stable polycrystalline diamond matrix interspersed with fibers.

[0034] The fiber matrix may be provided as a laminate or woven pre-form. The fibers are laid out or woven into the desired orientations, such as by a weaving machine passing fibers through a screen. The fibers may be set in place with an epoxy and heated or pressed into a single sheet or ply, referred to as a pre-preg (pre-impregnated with epoxy or resin) which can be pyrolyzed by heating to essentially a pure carbon material for subsequent conversion to diamond. Multiple fiber pre-form sheets with desired fiber orientations can be used. If the stresses in the final end-use application are expected to be applied in one main direction, the fibers may be oriented parallel to each other in one main direction. If the stresses are expected to be more unpredictable, the fibers may

be interwoven in many different directions. Thus, the fibers may be oriented in a pre-determined, desired orientation prior to mixing with the ultra-hard diamond material. The fiber pre-forms or pre-pregs may be purchased commercially from a supplier such as Fiber Materials, Inc. (Biddeford, Me.). The fibers may be oriented randomly throughout the matrix in the form of shorter fiber sections (commonly known as “whiskers”) which are for example 100-500 microns long. In this case the composite material can be made from a graphite powder that is homogeneously blended with the fibrous whiskers to remove the need for fiber preforms or weaving.

[0035] In an example embodiment, the fiber pre-forms are stacked on top of each other in the desired configuration to form a fiber matrix for the diamond construction. Each fiber pre-form may be rotated with respect to the underlying fiber pre-form in order to build a network of fibers extending in multiple directions. In one embodiment the fiber pre-forms are sheets of woven fibers, with holes or gaps extending between the fibers through the sheets. That is, the sheets are not solid. When the sheets are stacked together, they form a framework of fibers with passages extending between the fibers through the stacked sheets.

[0036] Next, the method includes infiltrating the fiber matrix with graphite, such as by chemical vapor deposition or chemical vapor infiltration. Chemical vapor deposition or infiltration can be accomplished by flowing a process gas such as methane or hydrogen (or a mixture of these), which acts as a chemical precursor and reacts to deposit graphite on the surface of the fiber matrix. The graphite is deposited layer by layer until it fills the spaces between the overlaid fibers. This process may be done at a temperature of about 600-700° C. or higher.

[0037] In an embodiment, various forms of pure carbon are mechanically blended together and then laminated with the fibers, rather than being deposited by chemical vapor deposition. The carbon may be graphite, diamond, and other forms of carbon such as amorphous carbon, fullerenes (buckyballs/C60, nanotubes/fibers, etc.) or combinations of these. The carbon is mechanically blended using various methods such as ball or attritor milling, ultrasonic mixing, etc. In an embodiment, the mixture is further blended with polymers such as polyethylene carbonate or polypropylene carbonate, in preparation for making laminates. This carbon/polymer mixture is then combined with a fiber pre-form to make a laminate, as illustrated in FIGS. 7a and 7b. FIG. 7a shows a top view of a fiber preform 54 (as described above), and FIG. 7b shows a side view and indicates the process for combining the fiber pre-form with the carbon/polymer blend. The fiber preform 54 is shown as a row of fibers, for clarity, but it should be understood that the fibers may also be arranged in weaves or plies, with fibers extending in multiple directions. In FIG. 7b, a mixture 50 of graphite powder and polymer binder is spread over the preform 54 and smoothed by a blade 52. The carbon/polymer mixture 50 may be combined with the fiber preform 54 by any suitable tape casting technique, such as the doctor blade method illustrated in the figure, to form a laminate. This lamination process may be repeated to stack layers of fiber pre-form and carbon mixture until the appropriate thickness is achieved. The polymers are removed using conventional thermal outgassing methods (exposure to temperatures 300-1000 C in a vacuum or inert gas environment), and then the laminates are ready for exposure to HPHT treatment, as described below.

[0038] Thus, the desired forms of carbon and the fibers are combined together, such as by chemical vapor deposition or lamination, as described above. The carbon and fiber matrix can then be cut into the desired shape, to fit into an ultra-high pressure press. Next, the method includes HPHT sintering the carbon and fiber matrix without a catalyst material. This involves HPHT sintering at ultra-high temperature and pressure, above that applied during conventional HPHT sintering to form PCD. In one embodiment, the pressure is between about 100-160 kbar, such as about 150 kbar, and the temperature is about 1800-2500° C. For example, when sintering graphite, the pressure may be about 150 kbar, or about 150-160 kbar. When sintering other types of carbon, such as buckeyballs or other complex carbon structures, the pressure may be about 110-120 kbar. For reference, conventional HPHT sintering to form PCD may be performed at about 50-60 kbar.

[0039] The method phase transforms the graphite into polycrystalline diamond. That is, during the HPHT sintering process, the graphite converts into polycrystalline diamond, without the assistance of a catalyst material. Once the HPHT sintering is complete, the result is a thermally stable polycrystalline diamond matrix interspersed with reinforcing fibers. The fibers extend through the diamond matrix in the directions pre-selected by the arrangement of the fiber pre-form sheets.

[0040] Optionally, a second HPHT sintering process at conventional temperatures and pressures may be performed in order to incorporate the fiber-reinforced thermally stable polycrystalline diamond construction into a PCD body with a substrate. The fiber-reinforced thermally stable polycrystalline diamond construction may be cut into a desired shape, such as by electrical discharge machining (EDM) or laser cutting methods, and then strategically placed within a diamond powder mixture next to a substrate in a high-pressure press. The fiber-reinforced thermally stable polycrystalline diamond construction, the diamond powder mixture, and the substrate are then subjected to a conventional HPHT sintering process to convert the diamond powder into PCD, with the fiber-reinforced thermally stable polycrystalline diamond construction incorporated into the PCD body. In one embodiment, the fiber-reinforced thermally stable polycrystalline diamond construction forms at least a portion of the cutting edge of the diamond body.

[0041] An example of a cutting element 30 incorporating a fiber-reinforced thermally stable polycrystalline diamond construction 100 is shown in FIG. 5. The cutting element 30 includes a substrate 32 and a diamond body 34 bonded to the substrate. The diamond body 34 includes two regions—a first region 36 formed of PCD and a second region 38 formed from the fiber-reinforced thermally stable polycrystalline diamond construction 100. Both regions 36 and 38 form part of the cutting edge 16 of the diamond body 34. The second region 38 may form about 25% of the cutting edge (by circumference) as shown in FIG. 5, or up to 50%, or up to 100%. In other embodiment, the second region may form any portion of the cutting edge. In one embodiment, a second region 38a may be incorporated as for example shown by the dashed lines in FIG. 5. With this embodiment, the cutting element may be re-used after the cutting edge region 38 has worn by rotating the cutting element so as to place the cutting edge of region 38a into position to do the cutting. In another embodiment, a region 38b formed from the fiber-reinforced thermally stable polycrystalline diamond construction 100 may form any

upper portion of the diamond body. The upper portion may be limited to only an upper section (as for example an upper section occupying only region **38** and/or **38a**), or may span the entire upper section of the diamond body. In a further embodiment multiple regions **38** formed from the fiber-reinforced thermally stable polycrystalline diamond construction **100** may be located throughout the diamond body **34**. In another embodiment the entire diamond body may be formed from the fiber-reinforced thermally stable polycrystalline diamond construction **100**. With this latter embodiment, the diamond construction may not be placed in the diamond powder mixture. The size of the thermally stable polycrystalline diamond construction may be limited by the cell size of the press used to apply the high pressure to form the thermally stable polycrystalline diamond construction. In one embodiment, a majority of the fibers in the fiber-reinforced region **38** of the cutting element **30** are substantially intact, after the ultra-HPHT sintering process. FIG. **6** shows a drag bit **40** incorporating the cutting element of FIG. **5**, according to an example embodiment. The drag bit **40** may include several cutting elements **30** and may be used for high-temperature rock drilling operations. In other embodiments, other types of drilling or cutting tools incorporate cutting elements that have a fiber-reinforced thermally stable diamond matrix forming at least a portion of the cutting edge of the cutting element. For clarity, the fiber-reinforced region **38** is shown on two of the cutting elements **30** in FIG. **6**, to indicate an example orientation of the fiber-reinforced region **38** on the blade **40**. It should be understood that other configurations and orientations may be used.

[0042] Both the manufacturing process and the final operating conditions for the diamond construction place great demands on the fibrous materials themselves. The fibers should be stronger and more ductile than the diamond matrix, and also need to be able to survive the extremely high pressures and temperatures of the ultra-HPHT sintering process described above, without deteriorating or reacting with the diamond. For example carbon fibers are known as desirable reinforcing fibers in some applications, but carbon fibers would not survive the ultra-HPHT sintering process. Instead, they would convert to diamond, and the fiber structure would deteriorate.

[0043] A majority of the fibers **120** remain substantially intact after the ultra-HPHT sintering process. The fibers **120** may be made of any material that has a critical strain greater than that of the polycrystalline diamond matrix material. In this context, critical strain means the failure stress divided by the elastic modulus of the material. The fibers should also be made of a material that is thermally stable at the ultra-high temperatures and pressures of the HPHT sintering process used to form the thermally stable polycrystalline diamond. For example, in various embodiments, the fibers **120** may be made of silicon carbide, magnesium aluminosilicate, alumina, sapphire, or combinations of these. In one embodiment, the fibers **120** are not made of carbon. In one embodiment, the fibers **120** are non-metal. In one embodiment, the fibers are cylindrically shaped, and about 10 microns in diameter. The length of the fibers depends on the particular diamond construction that is being formed, as the fibers may extend across the length or diameter of the diamond construction. In one embodiment, the fibers occupy about 5-30% (by volume) of the diamond construction. In general, the lower the percentage of fibers, the lower the resulting toughness in the diamond construction. However, if the fiber content is decreased too

much, such as below 5%, the beneficial properties contributed by the diamond matrix may be reduced.

[0044] In one embodiment, the fiber-reinforced thermally stable diamond construction is thermally stable above 700° C., and in another embodiment above 750° C., and maintains high strength at elevated temperatures (for example, a strength of about 3.0 GPa above 1000° C.). In one embodiment, the polycrystalline diamond matrix has a hardness of about 4000 HV or greater.

[0045] In one embodiment, the fibers are coated prior to weaving or laying them into the desired pre-form or pre-preg. The coating is designed such that it is able to de-bond from the diamond matrix in order to absorb stress applied to the material. This enables the diamond construction to absorb stress by de-bonding this coating rather than by cracking the diamond matrix. Thus, while the diamond matrix and the fibers are both strong, the interface between the two is designed to be relatively weak. To accomplish this, the fibers may be coated with a weak oxide material such as magnesium oxide, cobalt oxide, or nickel oxide. The coating may be from a few nanometers in thickness to 1-2 microns in thickness. The coating is applied prior to arranging the fibers together in the desired or random orientation to form the fiber sheets or laminates. Fiber pre-pregs with coated fibers may be pre-manufactured and available for purchase. Other oxides that may be used alone or in combination with other material coatings are zirconium oxide, silicon dioxide, titanium dioxide, and aluminum oxide. Carbides of silicon, titanium, vanadium, chromium, zirconium, niobium, molybdenum, hafnium, tantalum, and tungsten may also be used alone or in combination with other coating materials. In addition, silicates such as Yb₂SiO₅, Yb₂SiO₇, Ho₂Si₂O₇, Re₂Si₂O₇, or LaMgAl₁₁O₁₉ may also be employed in fiber coatings.

[0046] In an alternate embodiment, carbonate PCD, another type of thermally stable diamond, is reinforced with fibers to provide increased toughness. Carbonate PCD is a thermally stable form of PCD, in which magnesium carbonate or calcium carbonate is used as the catalyst material, rather than cobalt or another solvent metal. The magnesium carbonate or calcium carbonate is more thermally stable than other types of catalysts, as the carbonate catalyst does not catalyze conversion of carbon to graphite, which metal catalysts are prone to do. In this case, rather than using chemical vapor deposition or infiltration to fill a fiber matrix with graphite, the fiber matrix pre-form sheets are alternated with carbonate PCD powder to build up a stack of fiber and diamond powder, as shown for example in FIG. **8**. FIG. **8** shows a partial cross-sectional view of a pre-sintered mixture **300** of carbonate diamond powder **302** with stacked pre-formed fiber layers **304**, according to an example embodiment. The diamond powder may be mixed with a polymer to form the powder into a uniform layer **302** for stacking. This stacked construction **300** is then HPHT sintered at about 80 kbar and about 2000° C. to form a fiber-reinforced thermally stable carbonate PCD construction.

[0047] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. It is the express intention of the application not to invoke 35 U.S.C. §112, paragraph 6 for any

limitations of any of the claims herein, except for those in which the claim expressly uses the words 'means for' together with an associated function.

What is claimed is:

1. A polycrystalline diamond construction, comprising: a diamond body having a thermally stable diamond matrix comprising bonded-together diamond crystals, wherein the diamond matrix comprises a diamond volume content of at least 99%; and a plurality of fibers extending through the thermally stable diamond matrix.
2. The polycrystalline diamond construction of claim 1, wherein the fibers comprise a strain to failure greater than that of the diamond crystals.
3. The polycrystalline diamond construction of claim 1, wherein the fibers comprise silicon carbide, alumina, sapphire, or magnesium aluminosilicate.
4. The polycrystalline diamond construction of claim 1, wherein the fibers are oriented in a pre-determined orientation in the thermally stable diamond matrix.
5. The polycrystalline diamond construction of claim 1, wherein the fibers are randomly oriented in the thermally stable diamond matrix.
6. The polycrystalline diamond construction of claim 1, wherein the diamond crystals are thermally stable above 700° C.
7. The polycrystalline diamond construction of claim 1, wherein the fibers comprise a coating providing an interface between the fibers and the diamond crystals that is weaker than the diamond matrix.
8. The polycrystalline diamond construction of claim 7, wherein the coating comprises an oxide, carbide, or silicide material.
9. The polycrystalline diamond construction of claim 1, wherein the plurality of fibers occupy about 5-30% by volume of the diamond body.
10. The polycrystalline diamond construction of claim 9, wherein the thermally stable diamond matrix occupies the remaining 70-95% by volume of the diamond body.

11. A shear cutter, comprising the polycrystalline diamond construction of claim 1, directly or indirectly bonded to a substrate.

12. A drag bit comprising a body having the shear cutter of claim 9, mounted thereon.

13. A method of forming a fiber-reinforced thermally stable polycrystalline diamond construction, comprising: providing a fiber matrix; infiltrating the fiber matrix with graphite; and HPHT sintering the graphite and the fiber matrix at ultra-high temperature and pressure, without a catalyst material.

14. The method of claim 13, wherein HPHT sintering includes phase-transforming the graphite into polycrystalline diamond.

15. The method of claim 13, wherein the ultra-high temperature and pressure comprise a temperature of about 1800-2500° C. and a pressure of about 100-160 kbar.

16. The method of claim 13, further comprising orienting the fibers in a pre-determined orientation prior to infiltrating.

17. The method of claim 13, further comprising randomly orienting the fibers prior to infiltrating.

18. A polycrystalline diamond construction, comprising: a diamond body having a diamond matrix comprising bonded-together diamond crystals and interstitial spaces between the diamond crystals, and comprising a carbonate catalyst disposed within the interstitial spaces; and a plurality of fibers extending through the diamond matrix.

19. The diamond construction of claim 18, wherein the fibers are oriented in stacked layers in the diamond body.

20. A shear cutter, comprising the polycrystalline diamond construction of claim 18, directly or indirectly bonded to a substrate.

21. A drag bit comprising a body having the shear cutter of claim 18, mounted thereon.

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