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(54) **MATRIX DRILL BIT WITH DUAL SURFACE COMPOSITIONS AND METHODS OF MANUFACTURE**

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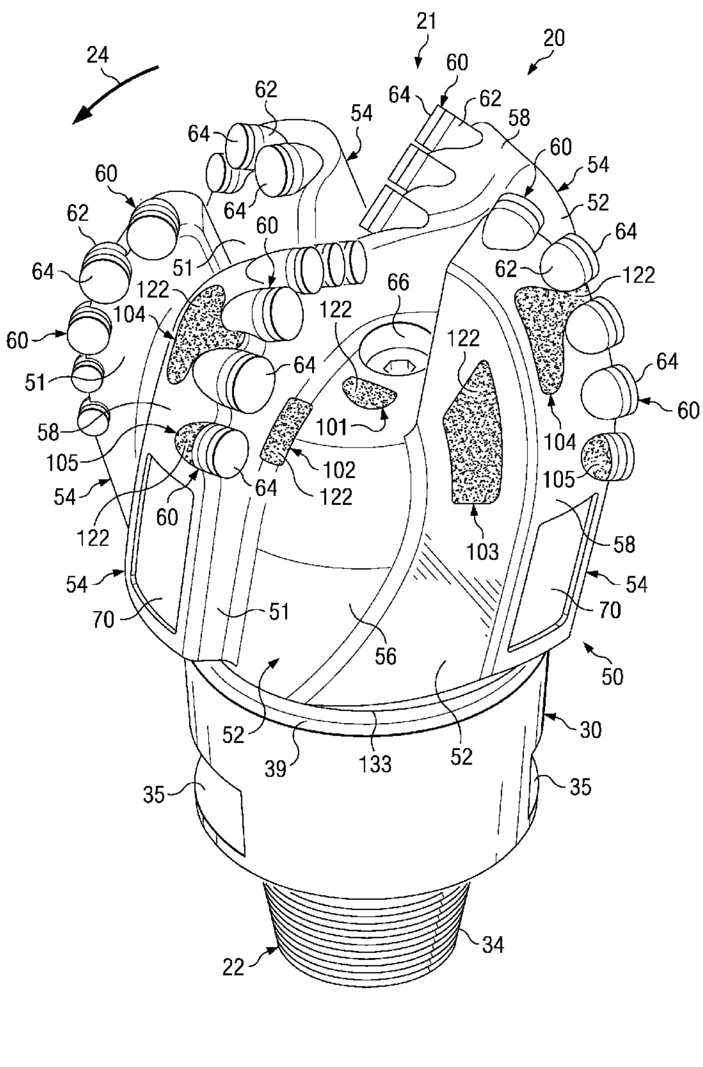
USPC **51/297**; 51/307

(57) **ABSTRACT**

Matrix drill bits and other downhole tools may be formed with one or more layers of hard materials disposed on exterior portions thereof. Exterior portions of used rotary drill bits or other downhole tools may be measured using three dimensional (3D) scanning techniques or other techniques to determine specific locations of undesired abrasion, erosion and/or wear. During the design of a new rotary drill bit or other downhole tool, computational flow analysis techniques may be used to determine potential locations for excessive erosions, abrasion, wear, impact and/or fatigue on exterior portions of the rotary drill bit or other downhole tools. One or more layers of hard material may be disposed at such locations on exterior portions of matrix bit bodies and other matrix bodies based on analyzing exterior portions of used downhole tools and/or computational flow analysis.



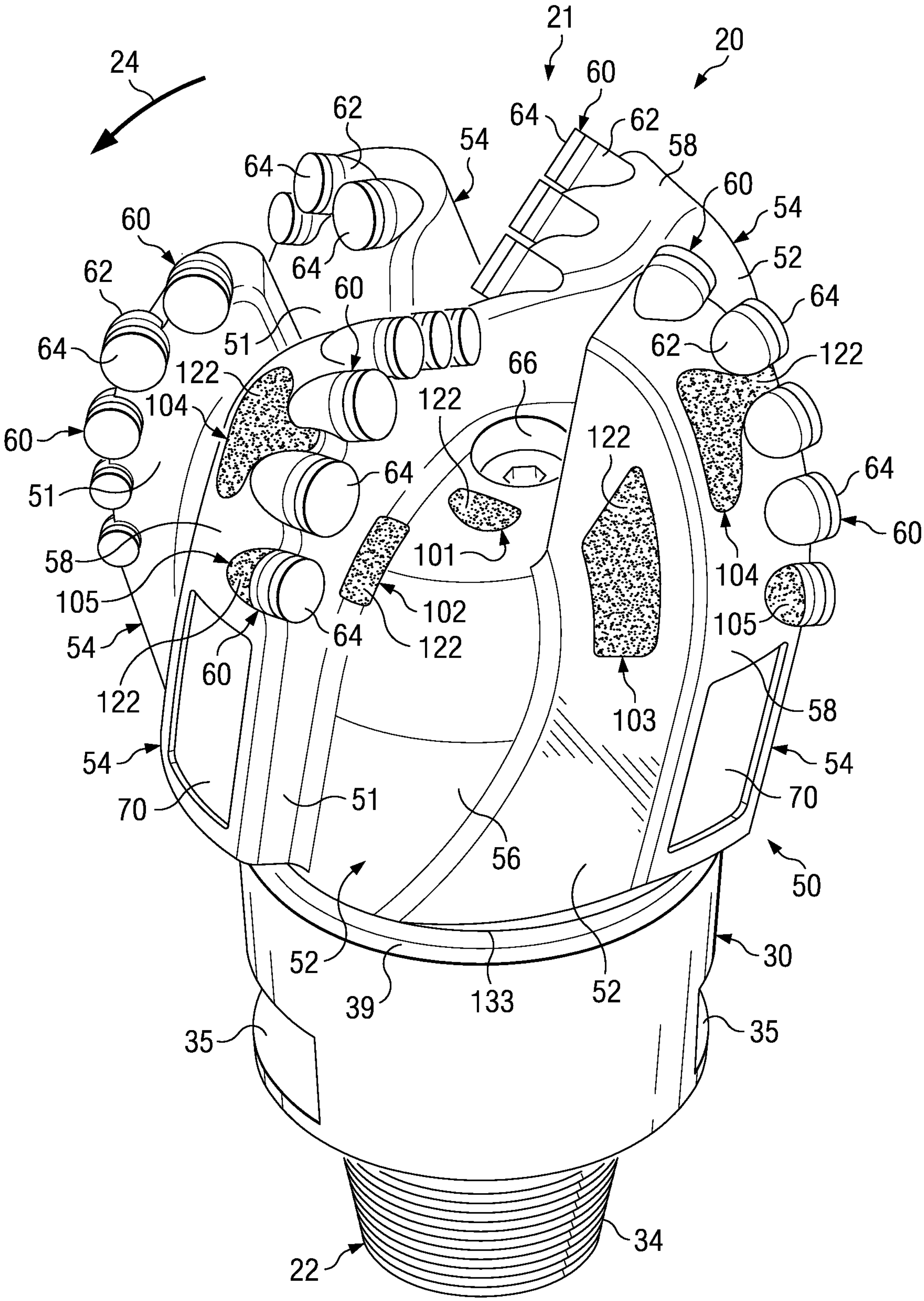

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FIG. 1

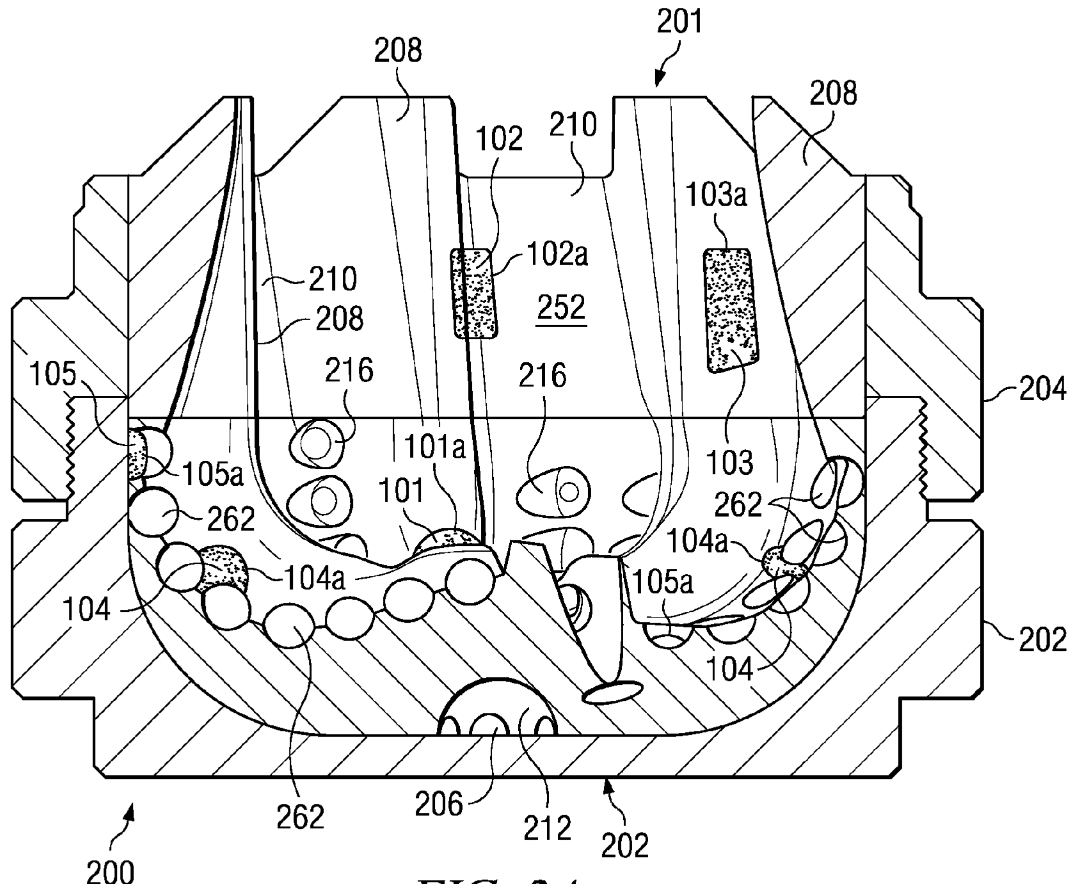
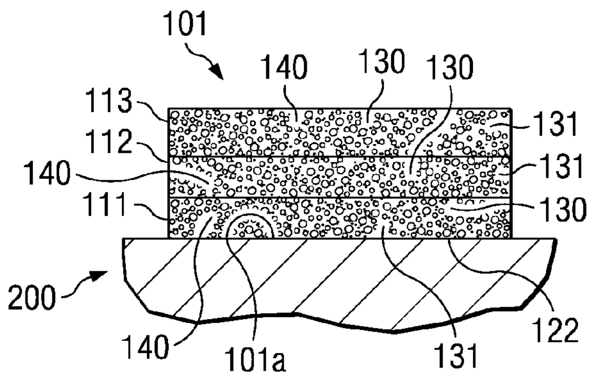


FIG. 2A



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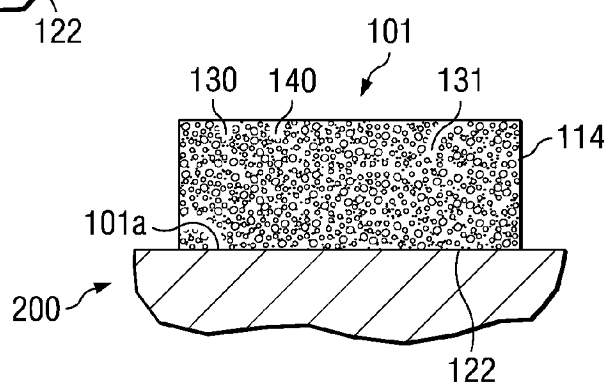

FIG. 2C

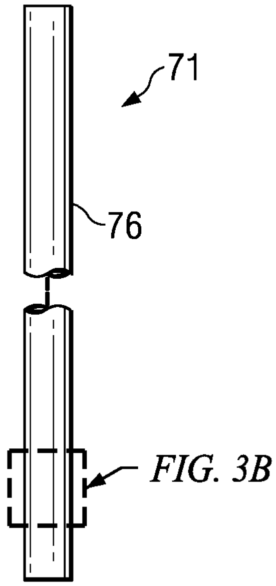

FIG. 3A

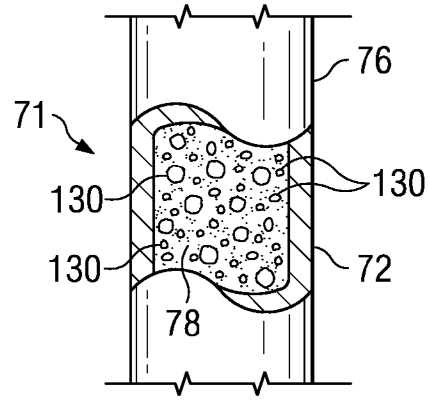

FIG. 3B

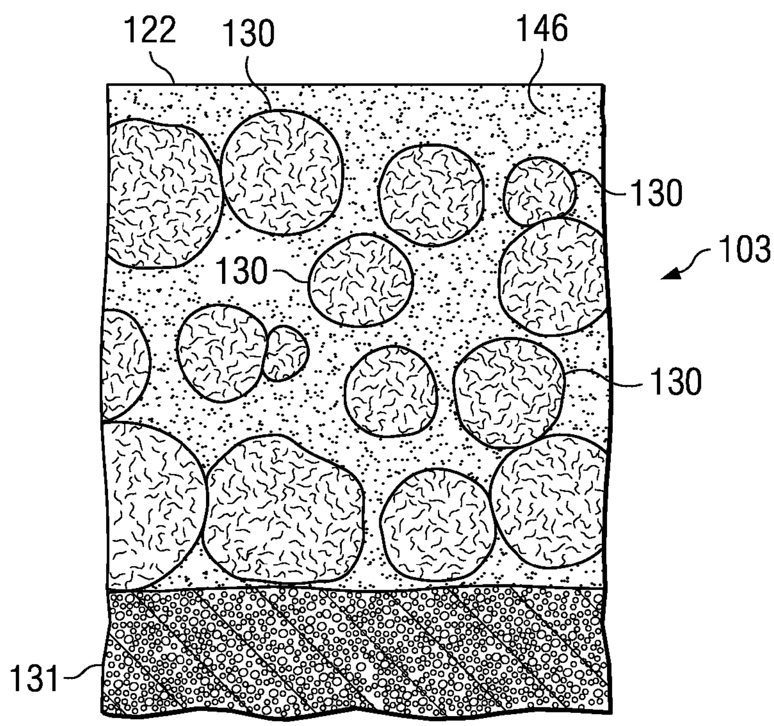

FIG. 3C

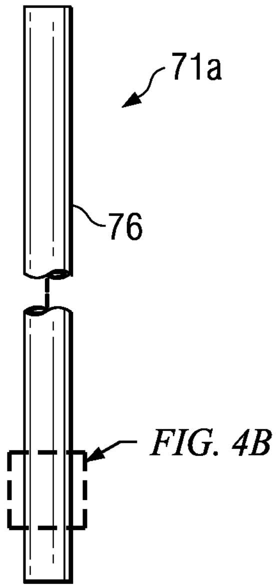

FIG. 4A

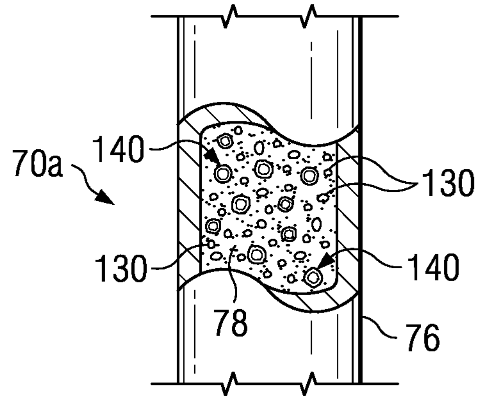

FIG. 4B

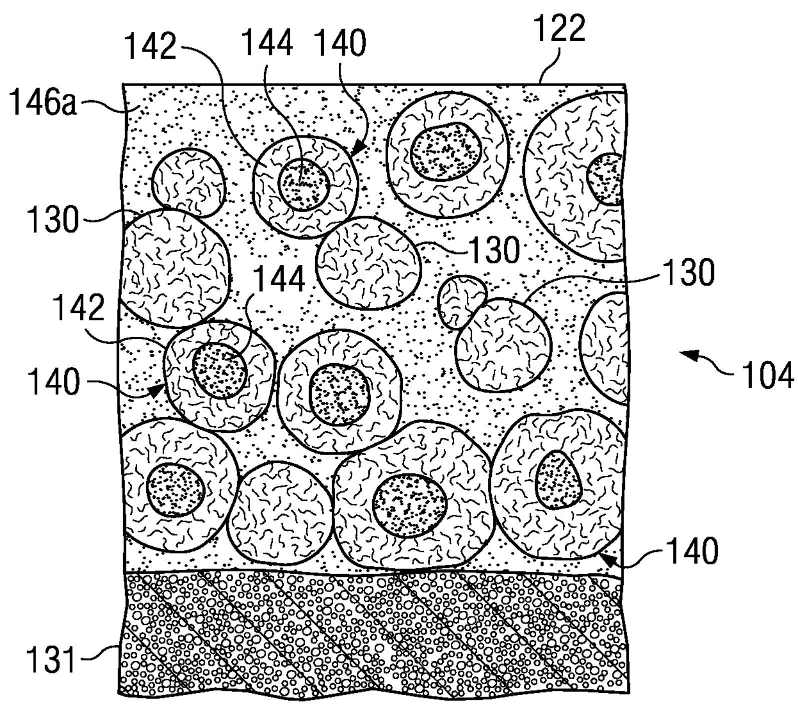

FIG. 4C

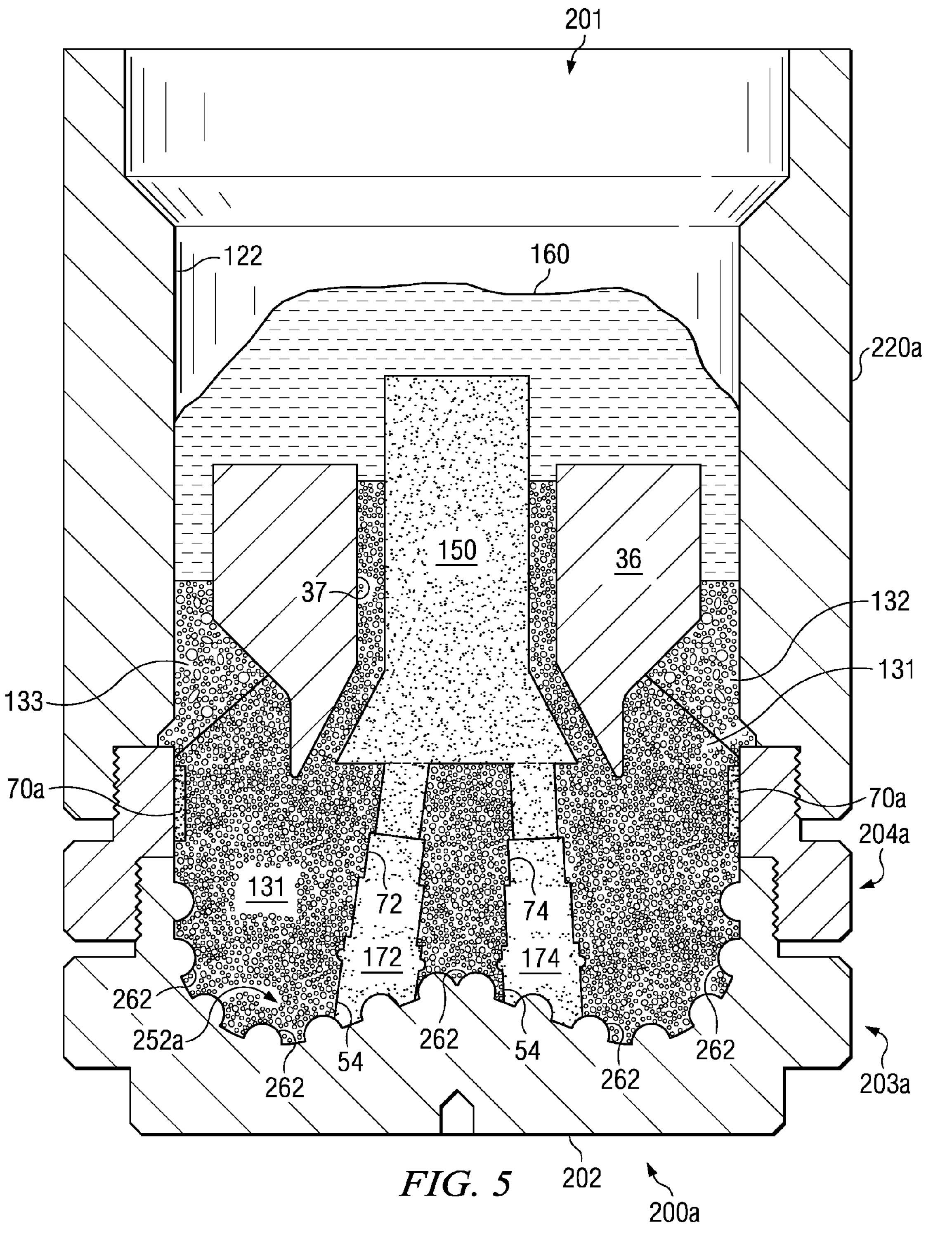
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FIG. 5

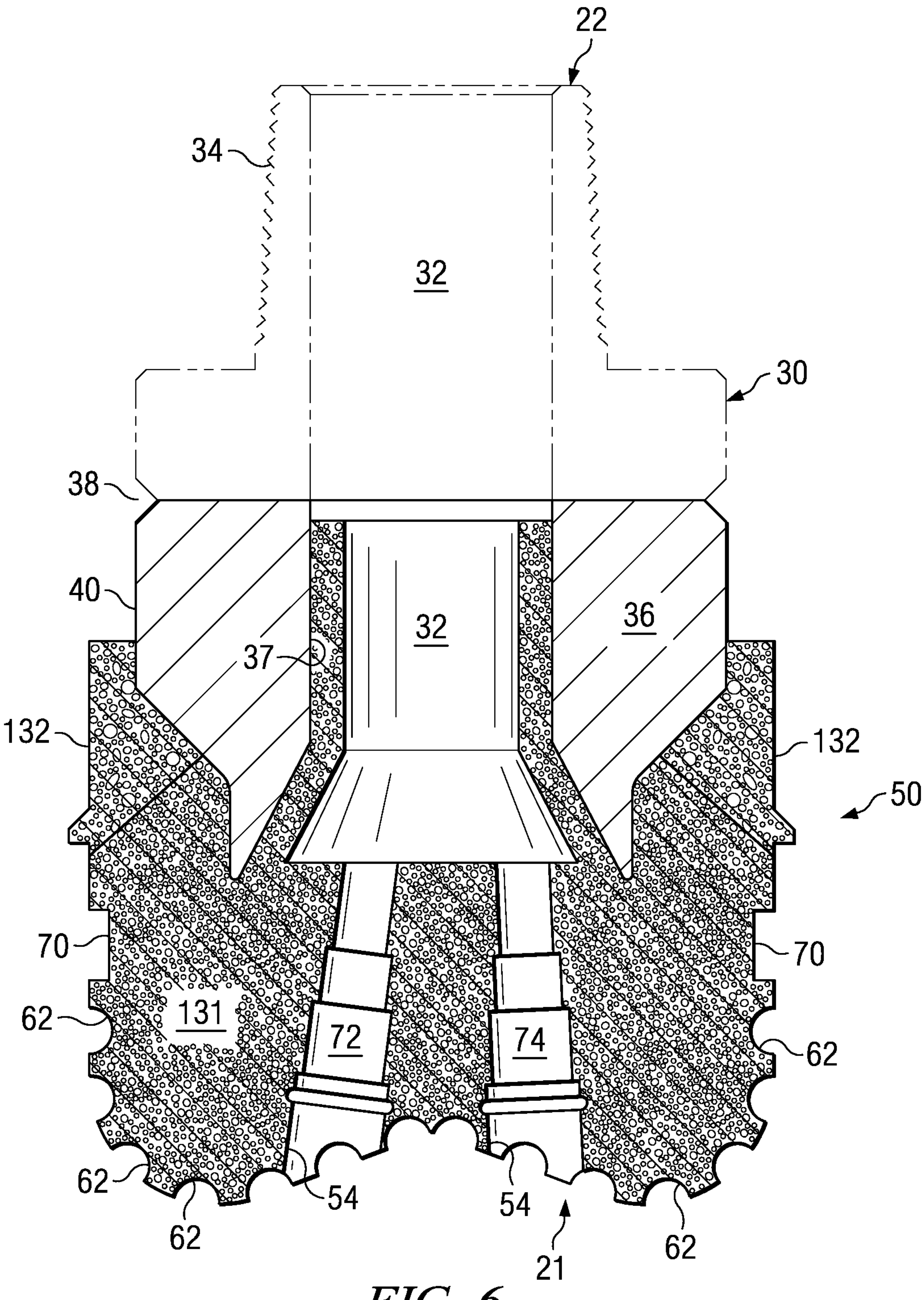
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FIG. 6

MATRIX DRILL BIT WITH DUAL SURFACE COMPOSITIONS AND METHODS OF MANUFACTURE

RELATED APPLICATION

[0001] This application claims the benefit of U.S. provisional application Ser. No. 61/148,665 entitled "Matrix Drill Bit With Dual Surface Compositions And Methods of Manufacture" filed Jan. 30, 2009, the contents of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates in general to matrix drill bits and other well tools with matrix bodies having one or more layers of hard material disposed at selected locations on exterior portions thereof and, more particularly, to forming one or more layers of hard material at selected locations during manufacture of a matrix body or applying one or more layers of hard material at selected locations on exterior portions of a used matrix body.

BACKGROUND OF THE DISCLOSURE

[0003] Rotary drill bits are frequently used to drill oil and gas wells, geothermal wells and water wells. Rotary drill bits may be generally classified as rotary cone or roller cone drill bits and fixed cutter drill bits or drag bits. Fixed cutter drill bits or drag bits may be formed with a matrix bit body having cutting elements or inserts disposed at select locations of exterior portions of the matrix bit body. Fluid flow passageways are typically formed in the matrix bit body to allow communication of drilling fluids from associated surface drilling equipment through a drill string or drill pipe attached to the matrix bit body. Such fixed cutter drill bits or drag bits may sometimes be referred to as "matrix drill bits."

[0004] Matrix drill bits are typically formed by placing loose matrix material (sometimes referred to as "matrix powder") into a mold and infiltrating the matrix material with a hot, liquid binder such as a copper alloy. The mold may be formed by various techniques including, but not limited to, milling a block of material such as graphite to define a mold cavity with features that correspond generally with desired features of the resulting matrix drill bit. Various features of the resulting matrix drill bit such as blades, cutter pockets, and/or fluid flow passageways may be provided by shaping the mold cavity, positioning one or more mold inserts within the mold cavity and/or by positioning temporary displacement materials within the mold cavity.

[0005] Since machining hard, abrasion, erosion and/or wear resistant materials is generally both difficult and expensive, it is common practice to form some metal parts with a desired configuration and subsequently treat one or more portions of the metal part to provide desired abrasion, erosion and/or wear resistance. Examples may include directly hardening such surfaces (carburizing and/or nitriding) one or more surfaces of a metal part or applying a layer of hard, abrasion, erosion and/or wear resistant material (hardfacing) to one or more surfaces of a metal part depending upon desired amounts of abrasion, erosion and/or wear resistance for such surfaces. For applications when resistance to extreme abrasion, erosion and/or wear of a working surface and/or associated substrate is desired, a layer of hard, abrasion, erosion and/or wear resistant material (hardfacing) be applied to the working surface to protect the associated substrate. Apply hard facing to matrix materials such as a matrix bit body is often more difficult and technically challenging as compared with applying the same hardfacing to a generally uniform, non-matrix metal surface.

[0006] Hardfacing may be generally defined as a layer of hard, abrasion resistant material applied to a less resistant surface or substrate by plating, welding, spraying or other well known deposition techniques. Hardfacing is frequently used to extend the service life of drill bits and other downhole tools used in the oil and gas industry. Tungsten carbide and various alloys of tungsten carbide are examples of hardfacing materials widely used to protect drill bits and other downhole tools associated with drilling and producing oil and gas wells.

[0007] A wide variety of hard materials have been applied to exterior portions of rotary drill bits and other downhole tools. Frequently used hard materials include, but are not limited to, sintered tungsten carbide particles in a steel alloy matrix deposit. Tungsten carbide particles may include grains of monotungsten carbide, ditungsten carbide and/or macrocrystalline tungsten carbide. Spherical cast tungsten carbide may typically be formed with no binding material. Examples of binding materials used to form tungsten carbide particles may include, but are not limited to, cobalt, nickel, boron, molybdenum, niobium, chromium, iron and alloys of these elements.

SUMMARY

[0008] The present disclosure provides matrix bit bodies for rotary drill bits or matrix bodies for other downhole tools with one or more layers of hard material disposed at selected locations to provide substantially enhanced resistance to erosion, abrasion, wear, impact and/or fatigue forces as compared with prior matrix bodies without such layers of hard material. In accordance with teachings of the present disclosure, such layers of hard material may include tungsten carbide particles, formed with an optimum amount of binding material, particles of other superabrasive and/or superhard materials. Examples of such hard materials satisfactory for use with the present disclosure may include, but are not limited to, encrusted diamond particles, coated diamond particles, silicon nitride (Si_3N_4), silicon carbide (SiC), boron carbide (B_4C) and cubic boron nitride (CBN). Such hard materials may also be used to rebuild exterior portions of used drill bits (sometimes referred to as "dull bits") in accordance with teachings of the present disclosure.

[0009] One or more layers of hard material may be disposed at selected locations on exterior portions of a matrix bit body associated with a matrix drill bit or at selected locations on other downhole tools in accordance with teachings of the present disclosure during molding of an associated matrix body and/or after molding of the associated matrix body. The resulting matrix body may be described as having a dual phase exterior or dual surface composition.

[0010] One aspect of the present disclosure may include placing one or more layers of one or more hard materials at selected locations in a mold corresponding generally with respective selected locations on exterior portion of blades, cutter pockets, junk slots and/or other components of an associated matrix bit body. A preformed hollow bit blank or casting mandrel may be disposed in the mold. One or more matrix materials may be added to the mold. The matrix materials may be selected to form a hard, matrix bit body. A binder material may also be added to the mold. During heating of the mold, liquid binder material may flow through the matrix

materials and the one or more layers of the hard material. The layer or layers of hard material may provide desired enhancement to resist erosion, abrasion, wear, impact and/or fatigue forces at respective selected locations on exterior portions of the matrix bit body.

[0011] For some applications, a composite layer of hard material may be disposed at selected locations on exterior portions of a matrix bit body in accordance with teachings of the present disclosure. Each composite layer of hard material may include two, three or more smaller (thinner) layers or sublayers of hard material. Each sublayer of hard material may include a plurality of large hard particles including, but not limited to, low alloy sintered materials in the form of pellets and/or low alloy sintered material in the form of crushed powder. Other forms of low alloy sintered material may also be used to enhance downhole drilling performance and/or associated matrix drill bit life.

[0012] For some applications, a low percentage of binder material (4% plus or minus 1% Co, Ni, B, Mo, Cr or Se binder or any combination thereof) may be used to bind fine tungsten carbide grains to form generally spherical tungsten carbide particles or pellets. The use of such particles or pellets may provide substantially increased carbide content at one or more selected locations on exterior portions of an associated matrix body as compared to hard materials with twenty to thirty percent (20% to 30%) binder. For some applications, the size of the resulting tungsten carbide particles or pellets may be substantially enlarged such that only one layer of the second hard material is required to provide satisfactory resistance to erosion, abrasion, impact and/or fatigue forces at a selected location. Used matrix drill bits may be repaired by forming one or more layers of hard material at selected locations on exterior portions of an associated matrix bit body.

[0013] For some applications, one or more layers of the low alloy sintered material may also include matrix materials used to form an associated matrix bit body. Various binding processes including, but not limited to, sintering and/or sinter-hipping may be used to form spherical tungsten carbide particles or pellets in a sintering furnace. For some applications a sintered tungsten carbide pellet may be used in combination with conventional matrix materials to form a matrix drill bit. Such materials may be used to rebuild a matrix bit body in accordance with teachings of the present disclosure.

[0014] Various techniques may be satisfactorily used to determine the location or locations for forming one or more layers of hard material on exterior portions of an associated matrix body. For example, simulation of fluid flow over exterior portions of a matrix drill bit or other downhole tools having a matrix body in combination with analysis of wear patterns on exterior portions of an associated matrix drill bit and/or other downhole tools may help to identify one or more locations for forming such layers of hard material. Three dimensional (3D) scanning of used drill bits, visual inspection or other techniques may also be used to select locations for forming one or more layers of hard material with enhanced erosion, war, abrasion, impact and/or fatigue resistance on exterior portions of a matrix bit body during manufacture of an associated matrix drill bit.

[0015] Matrix materials including, but are not limited to, cemented carbides of tungsten, macrocrystalline tungsten carbide, tungsten cast carbide, titanium, tantalum, niobium, chromium, vanadium, molybdenum, hafnium independently or in combination and/or spherical carbides may be used to form one or more layers of hard material at selected locations matrix bodies in accordance with teachings of the present disclosure. However, the present disclosure is not limited to cemented tungsten carbides, spherical carbides, macrocrystalline tungsten carbide and/or cast tungsten carbides or mixtures thereof.

[0016] Some embodiments one or more layers of hard material may be disposed on exterior portions of a matrix body with at least one layer having both large particles or pellets and small particles or pellets. The ratio of larger pellets to small pellets may vary from approximately one to one or fifty percent large pellets and fifty percent small pellets to approximately three (3) large pellets for every small pellet (3 to 1) or seventy five percent (75%) large pellets and twenty five percent (25%) small pellets. The size of a typical small pellet of hard material may be approximately 20 mesh (850μ) to 30 mesh (600μ). The size of a typical large pellet of hard material may be approximately 16 mesh (1180μ) to 20 mesh (850μ).

[0017] Additional features, steps, technical advantages and/or benefits of the present disclosure may be discussed in the Detailed Description and/or Claims. The above Summary is not intended to be a comprehensive listing of all features, steps, technical advantages and/or benefits of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] For a more complete understanding of the present disclosure and its advantages thereof, reference is now made to the following brief descriptions, taken in conjunction with the accompanying drawings and detailed description, wherein like reference numerals represent like parts, in which:

[0019] FIG. **1** is a schematic drawing showing an isometric view of one example of a matrix drill bit having a matrix bit body with one or more layers of hard material disposed at selected locations on exterior portions of the matrix bit body;

[0020] FIG. **2**A is a schematic drawing in section with portions broken away showing a mold assembly satisfactory to form a matrix body in accordance with teachings of the present disclosure;

[0021] FIG. **2**B is a schematic drawing showing multiple layers of hard material or a composite layer of hard material which may be disposed at one or more locations on interior portions of the mold shown in FIG. **2**A;

[0022] FIG. **2**C is a schematic drawing in section with portions broken away showing a single layer of hard material which may be disposed at one or more locations on interior portions of the mold shown in FIG. **2**A;

[0023] FIG. **3**A is a schematic drawing in elevation with portions broken away showing a welding rod with hard materials disposed therein in accordance with teachings of the present disclosure;

[0024] FIG. **3**B is an enlarged schematic drawing in section with portions broken away showing tungsten carbide pellets and other hard materials disposed within the welding rod of FIG. **3**A;

[0025] FIG. **3**C is an enlarged schematic drawing in section with portions broken away showing tungsten carbide pellets formed with an optimum weight percentage of binding material and bonded to a matrix deposit disposed on and bonded to a substrate or matrix body in accordance with teachings of the present disclosure;

[0026] FIG. **4**A is a schematic drawing in elevation with portions broken away showing a welding rod with hard materials disposed therein in accordance with teachings of the present disclosure;

[0027] FIG. **4**B is an enlarged schematic drawing in elevation and in section with portions broken away showing tungsten carbide pellets, encrusted diamond particles and other hard materials disposed within the welding rod of FIG. **4**A;

[0028] FIG. **4**C is an enlarged schematic drawing in section with portions broken away showing tungsten carbide pellets formed with an optimum weight percentage of binding material along with encrusted diamond particles and bonded to a matrix deposit disposed on and bonded to a substrate or matrix body in accordance with teachings of the present disclosure;

[0029] FIG. **5** is a schematic drawing in section with portions broken away showing a mold assembly with mold inserts, matrix materials and other materials disposed therein satisfactory to form a matrix bit body in accordance with teachings of the present disclosure; and

[0030] FIG. **6** is a schematic drawing in section with portions broken away showing a matrix bit body with recesses formed in exterior portions thereof in accordance with teachings of the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0031] Preferred embodiments and various advantages may be understood by referring in more detail to FIGS. **1-6** of the drawings, in which like numerals refer to like parts.

[0032] The terms "matrix bit", "matrix drill bit" and "matrix rotary drill bit" may be used in this application to refer to "rotary drag bits", "drag bits", "fixed cutter drill bits" or any other drill bit incorporating teaching of the present disclosure. Such drill bits may be used to form well bores or boreholes in subterranean formations.

[0033] Matrix drill bits incorporating teachings of the present disclosure may include a matrix bit body formed by one or more matrix materials. For other embodiments (not expressly shown) a matrix bit body may be formed with at least a first matrix material and a second matrix material. For some applications the first matrix material may have increased toughness or high resistance to fracture and also provide erosion, abrasion and wear resistance. The second matrix material (not expressly shown) with only a limited amount of alloy materials or other contaminates may also be used to form the matrix bit body. The first matrix material may include, but is not limited to, cemented carbides or spherical carbides. The second matrix material may include, but is not limited to, macrocrystalline tungsten carbides and/or cast carbides. One or more layers of hard material may be disposed at selected locations on matrix bodies formed from matrix materials in accordance with teachings of the present disclosure.

[0034] Various types of binder materials may be used to infiltrate matrix materials disposed in a mold to form a matrix bit body. Binder materials may include, but are not limited to, copper (Cu), nickel (Ni), cobalt (Co), iron (Fe), molybdenum (Mo) individually or alloys based on these metals. The alloying elements may include, but are not limited to, one or more of the following elements—manganese (Mn), nickel (Ni), tin (Sn), zinc (Zn), silicon (Si), molybdenum (Mo), tungsten (W), boron (B) and phosphorous (P). The matrix bit body may be attached to a hollow bit blank or casting mandrel. A generally hollow shank or hollow tool joint with a threaded connection may be attached to the hollow bit blank or casting mandrel for use in releasably engaging the associated matrix drill bit with a drill string, drill pipe, bottom hole assembly or downhole drilling motor (not expressly shown).

[0035] The terms "cemented carbide" and "cemented carbides" may be used within this application to include WC, MoC, TiC, TaC, NbC, Cr_3C_2, VC and solid solutions of mixed carbides such as WC—TiC, WC—TiC—TaC, WC—TiC–(Ta,Nb)C in a metallic binder (matrix) phase. Typically, Co, Ni, Fe, Mo and/or their alloys may be used to form the metallic binder. Cemented carbides may sometimes be referred to as "composite" carbides or sintered carbides. Some cemented carbides may also be referred to as spherical carbides. However, cemented carbides may have many configurations and shapes other than spherical.

[0036] Cemented carbides may be generally described as powdered refractory carbides which have been united by compression and heat with binder materials such as powdered cobalt, iron, nickel, molybdenum and/or their alloys. Cemented carbides may also be sintered, crushed, screened and/or further processed as appropriate. Cemented carbide pellets may be used to form a matrix bit body. The binder material may provide ductility and toughness which often results in greater resistance to fracture (toughness) of cemented carbide pellets, spheres or other configurations as compared to cast carbides, macrocrystalline tungsten carbide and/or formulates thereof.

[0037] Binder materials used to form cemented carbides may sometimes be referred to as "bonding materials" in this Application to help distinguish between binder materials used to form cemented carbides and binder materials used to form a matrix drill bit.

[0038] The terms "computational fluid dynamics" and/or "CFD" may be used in this application to include various commercially available computer programs and algorithms used to simulate and evaluate complex fluid interactions. Such simulations may include calculating mass transfer, turbulence, velocity changes and other characteristics associated with multiphase, complex fluid flow associated with a matrix drill bit forming a wellbore. Such fluids may often be a mixture of liquids, solids and/or gases with varying concentrations depending on associated downhole drilling conditions. Simulations using CFD programs may be used to determine optimum locations for forming one or more layers of hard material on exterior portions of a matrix body based on anticipated fluid flow for the type/size of pump used on an associated drilling rig (not expressly shown), size of associated drill string (not expressly shown), size and configuration of an associated matrix drill bit or other downhole tool and/or anticipated downhole drilling conditions.

[0039] The term "digital scanning" may be used to describe a wide variety of equipment and techniques satisfactory for measuring exterior dimensions of a matrix drill bit and other downhole tools with a very high degree of accuracy and to create a three dimensional image of exterior portions of such well tools. The results of digital scanning may be used with other computer programs such as "computational fluid dynamics" or CFD programs to evaluate fluid flow characteristics over exterior portions of matrix drill bits and other downhole tools.

[0040] Some examples of digital scanning equipment and techniques are discussed in U.S. Patent Application Ser. No. 60/992,392; Filing Date: Dec. 5, 2007, entitled "Method and

Apparatus to Improve Design, Manufacture, Performance and/or Use of Well Tools" now U.S. patent Ser. No. ______. CFD programs are available from various vendors. One example of a CFD program satisfactory for use with the present invention is FLUENT, available from ANSYS, Inc. located in Canonsburg, Pa.

[0041] Various computer programs and computer models may be used to design blades, cutting elements, fluid flow paths and/or associated rotary drill bits. Examples of such methods and systems which may be used to design and evaluate performance of cutting elements and rotary drill bits are shown in U.S. Patent Applications entitled "Methods and Systems for Designing and/or Selecting Drilling Equipment Using Predictions of Rotary Drill Bit Walk," application Ser. No. 11/462,898, filing date Aug. 7, 2006, (now U.S. patent Ser. No. ______); U.S. patent application entitled "Methods and Systems of Rotary Drill Bit Steerability Prediction, Rotary Drill Bit Design and Operation," application Ser. No. 11/462,918, filed Aug. 7, 2006, (now U.S. patent Ser. No. ______) and U.S. Patent Application entitled "Methods and Systems for Design and/or Selection of Drilling Equipment Based on Wellbore Simulations," application Ser. No. 11/462, 929, filing date Aug. 7, 2006, (now U.S. patent Ser. No. ______).

[0042] The terms "dual surface compositions", "dual exterior composition", dual phase surface" and/or "dual phase exterior" may be used to describe a matrix body having one or more layers of hard material disposed at selected locations on exterior portions of the matrix body. The matrix body may be formed from one or more matrix materials. Hard materials forming the layer or layers at the selected locations on exterior portions of the matrix body may generally have a hardness greater than the hardness of matrix materials used to form the associated matrix body.

[0043] The term "gage pad" as used in this application may include a gage, gage segment or gage portion disposed on exterior portion of a blade. Gage pads may often contact adjacent portions of a wellbore formed by an associated rotary drill bit. Exterior portions of blades and/or associated gage pads may be disposed at various angles, either positive or negative and/or parallel, relative to adjacent portions of a straight wellbore. A gage pad may include one or more layers of material formed in accordance with teachings of the present disclosure. One or more gage pads may be disposed on a blade.

[0044] The terms "matrix deposit" and/or "metallic matrix deposit" may refer to a layer or layers of hard material disposed at selected exterior portions of a matrix body and/or substrate to protect the matrix body and/or the substrate at the selected locations from abrasion, erosion, wear, impact and/or fatigue forces. A matrix deposit may also sometimes be referred to as "metallic alloy material" or as a "deposit matrix." Various binders and/or binding materials such as cobalt, nickel, copper, iron and alloys thereof may be used to form a matrix deposit with hard, abrasion resistant materials and/or particles dispersed therein and bonded thereto. Nickel based alloys with increased ductility may be used at locations subject to erosion and/or abrasion.

[0045] Various types of tungsten carbide particles and/or pellets having an optimum size and/or optimum weight percentage of binder or binding material may be included as part of a matrix deposit or layer of hard material incorporating teachings of the present disclosure. One or more layers of hard material may be formed on a matrix body from a wide range of hard metal alloys and other hard materials.

[0046] The term "tungsten carbide" may include monotungsten carbide (WC), ditungsten carbide (W_2C), macrocrystalline tungsten carbide.

[0047] The terms "tungsten carbide pellet," "WC pellet," "tungsten carbide pellets" and "WC pellets" may refer to nuggets, spheres and/or particles of tungsten carbide formed with an optimum size and/or weight percentage of binding material in accordance with the teachings of the present disclosure. The terms "binder", "binding material" and/or "binder materials" may be used interchangeably in this Application.

[0048] FIG. **1** is a schematic drawing showing one example of a fixed cutter drill bit or matrix drill bit having one or more layers of hard material disposed on exterior portion thereof in accordance with teachings of the present disclosure. Matrix drill bit **20** as shown in FIG. **1** may sometimes be referred to as a "rotary drill bit," "fixed cutter drill bit" or "drag bit". Matrix drill bit **20** may include matrix bit body **50** having a plurality of blades **54** extending radially therefrom. Respective fluid flow paths (sometimes referred to as "junk slots") **56** may be disposed between adjacent blades **54**. Each blade **54** may include respective leading surface **51** and trailing surface **52**. Arrow **24** indicates the general direction of rotation of rotary drill bit **20** relative to an associated bit rotational axis (not expressly shown) during formation of a wellbore (not expressly shown).

[0049] First end or downhole end **21** of matrix drill bit **20** may include a plurality of cutting elements **60** operable to engage downhole formation materials and remove such materials to form a wellbore. Each cutting element **60** may be disposed in respective pocket **62** formed on exterior portion **58** of respective blade **54**. Each cutting element **60** may include respective cutting surface **64** formed from hard materials satisfactory for engaging and removing adjacent downhole formation materials (not expressly shown).

[0050] Cutting elements **60** may scrape and gouge formation materials from the bottom and sides of a wellbore (not expressly shown) during rotation of matrix drill bit **20**. For some applications, various types of polycrystalline diamond compact (PDC) cutters may be satisfactorily used as cutting elements **60**. A matrix drill bit having PDC cutters may sometimes be referred to as a "PDC bit".

[0051] Second end **22** of matrix drill bit **20** may include shank or tool joint **30** operable to releasably engage matrix drill bit **20** with a drill string (not expressly shown), bottom hole assembly (not expressly shown) and/or a downhole drilling motor (not expressly shown) to rotate matrix drill bit **20** during formation of a wellbore. Shank **30** and associated bit blank **36** may be described as having respective generally hollow cylindrical configurations defined in part by a fluid flow passageway extending therethrough. See, for example fluid flow passageway **32** in FIG. **6**. Various types of threaded connections such as American Petroleum Institute (API) drill pipe connection or threaded pin **34** may be formed on shank **30** proximate second end **22** of matrix drill bit **20**. Shank **30** may also include bit breaker slots **35**.

[0052] Various techniques may be used to securely engage generally hollow shank **30** with portions of bit blank **36** extending from matrix bit body **50**. See for example FIGS. **1** and **6**. For example, weld **39** may be formed in groove **38** disposed between and extending around the perimeter of shank **30** and bit blank **36**.

[0053] For some applications each blade **54** may include respective recess **70** formed in exterior portion **58** of each blade **54**. The location and dimensions of each recess **70** may be selected to correspond generally with a selected location for forming a gage pad on associated blade **54**. FIGS. **5** and **6** show one example of techniques which may be satisfactorily used to form respective recess **70** at selected locations on exterior portion **58** of each blade **54**. One or more layers of hard material may be disposed within each recess **70** in accordance with teachings of the present disclosure.

[0054] FIGS. **3**A and **3**B and FIGS. **4**A and **4**B show examples of welding rods **71** and **71***a* which may be used to form one or more layers of hard material in recess **70** in accordance with teachings of the present disclosure. Welding rods **71** and **71***a* may also be used to repair or rebuild a used matrix drill bit or matrix body in accordance with teachings of the present disclosure.

[0055] One or more nozzle openings **66** may be formed in exterior portions of matrix bit body **50**. Respective nozzle **68** may be disposed in each nozzle opening **66**. Various types of drilling fluid may be pumped from surface drilling equipment (not expressly shown) through an associated drill string (not expressly shown) attached to threaded connection **34** of shank or tool joint **30** to fluid flow passageway **32** disposed within matrix bit body **50**. One or more fluid flow paths may be formed in matrix bit body **50** to communicate drilling fluid and/or other fluids to associated nozzle **68**. See for example fluid passageways **72** and **74** in FIG. **6**. For some embodiments, one or more layers **101** of hard material may be disposed on exterior portions of matrix bit body **50** adjacent to nozzle opening **66**. See for example FIG. **1**.

[0056] One or more layers of hard material **102** may be disposed on exterior portions of one or more blades **54** proximate a transition or junction between adjacent junk slot **56** and associated leading surface **51**. One or more layers **103** of hard material may be disposed on trailing surface **52** of one or more blades **54**. In a similar manner, one or more layers **104** of hard material may be disposed on exterior portion **58** of each blade **54** proximate associated pockets **62** and/or cutting elements **60**. One or more layers **105** of hard material may be disposed exterior portions of selected pockets **62**. Respective locations, dimensions and configurations for layers **101**, **102**, **103**, **104** and **105** and associated hard materials on new matrix drill bits and/or used matrix drill bits may be selected using CFD analysis, digital scanning, visual scanning and drill bit design techniques in accordance with teachings of the present disclosure.

[0057] U.S. Pat. No. 6,296,069 entitled Bladed Drill Bit with Centrally Distributed Diamond Cutters and U.S. Pat. No. 6,302,224 entitled Drag-Bit Drilling with Multiaxial Tooth Inserts show various examples of blades and/or cutting elements which may be used with a matrix bit body incorporating teachings of the present disclosure. It will be apparent to persons having ordinary skill in the art that a wide variety of fixed cutter drill bits, drag bits and other drill bits may be satisfactorily formed with a matrix bit body incorporating teachings of the present disclosure. The present disclosure is not limited to matrix drill bit **20** or any specific features as shown in FIGS. **1-6**.

[0058] A wide variety of molds may be satisfactorily used to form a matrix bit body and associated matrix drill bit in accordance with teachings of the present disclosure. Mold assembly **200** shown in FIG. **2**A and mold assembly **200***a* shown in FIG. **5** represents only two examples of mold assemblies satisfactory for use in forming a matrix bit body incorporating teachings of the present disclosure. U.S. Pat. No. 5,373,907 entitled Method And Apparatus For Manufacturing And Inspecting The Quality Of A Matrix Body Drill Bit shows additional details concerning mold assemblies and conventional matrix bit bodies.

[0059] Layers **101**, **102**, **103**, **104** and **105** of various hard materials may be placed in mold assembly **200** at locations **101***a*, **102***a*, **103***a*, **104***a* and **105***a* corresponding generally with selected locations for forming corresponding layers of hard material on exterior portions of matrix drill bit **20**. One or more layers **101-105** of hard material may be disposed at each location in accordance with teachings of the present disclosure. For some applications a composite layer or multiple layers of hard material may be disposed at each location in mold assembly **200**. See for example FIG. **2**B. For other applications a single layer of hard material may be disposed at each location in mold assembly **200**. See for example FIG. **2**C.

[0060] Mold assemblies **200** and **200***a* as shown in FIGS. **2**A, **5** and **6** represent only two examples of molds and/or mold assemblies which may be satisfactorily used to form a matrix body incorporating teachings of the present disclosure. Mold assemblies **200** and **200***a* may be generally described as having cylindrical configurations defined in part by respective first, opened end **201** and second, closed end **202** with respective mold cavity **252** and **252***a* disposed there between. Mold cavities **252** and **252***a* may be generally described as negative images or inverse images of a matrix bit body formed by the respective mold assemblies **200** and **200***a*.

[0061] For some embodiments, interior portions of mold cavities **252** and/or **252***a* may be coated with a mold wash to prevent gasses, produced by heating and/or cooling of associated mold assemblies **200** and **200***a*, from entering into matrix materials disposed within respective mold cavities **252** and **252***a*. Various commercially available mold washes may be satisfactorily used. Mold assemblies **200** and/or **200***a* may also be placed within a container (not expressly shown). Interior portions of such containers may be designed to receive exterior portions of mold assemblies **200** and/or **200***a*. Such containers may sometimes be referred to as a "housing", "crucible" and/or "bucket".

[0062] Mold assembly **200** as shown in FIG. **2**A may include a plurality of displacements **208** disposed on interior portions of mold cavity **252**. The configuration and dimensions associated with each displacement **208** may be selected to generally correspond with blades **54** and fluid flow paths **56** formed on exterior portions of matrix bit body **50**.

[0063] Depending on the type of materials used to form mold assembly **200** and/or heating and cooling cycles associated with forming matrix bit body **50**, out gassing may occur. For such applications, a plurality of internal flow paths (not expressly shown) may be formed within mold assembly **200**. Such fluid flow paths may communicate gasses associated with heating and cooling of mold assembly **200** through fluid flow channels **206** and/or exterior portions of mold assembly **200**.

[0064] Mold cavity **252** as shown in FIG. **2**A may be formed with a plurality of negative blade profiles **210** disposed between respective displacements **208**. For some applications, mold assembly **200** and associated components may be formed using a 3D printer in combination with 3D design data. A plurality of negative pocket recesses or pocket profiles

262 may be formed within each negative blade profile 210. Negative pocket recesses 262 may have complex configurations and/or orientations as desired for respective pocket 62 and associated cutting element 60.

[0065] Locations 101*a*-105*a* within mold assembly 200 may be selected to correspond generally with locations on exterior portions of associated matrix drill bit 20 where high erosion, abrasion, wear, impact and/or fatigued forces may be applied. For example, one or more layers of hard material may be disposed at location 101*a* to minimize erosion from fluid flowing from associated nozzle 68. One or more layers of hard material may be disposed at locations 102*a* and 103*a* to minimize abrasion and/or wear associated with fluid flowing through associated flow path or junk slot 56. One or more layers of a second hard material may be disposed at locations 104*a* to minimize erosion, abrasion, wear, impact and/or fatigue forces applied to exterior portions 58 of associated blade 54 during engagement of associated cutting elements 60 with adjacent downhole formation materials. One or more layers of hard material may be disposed at location 105*a* on exterior portions of associated pocket 62 to minimize erosion, abrasion, wear, impact and/or fatigue forces resulting from respective cutting element 60 engaging and removing downhole formation materials.

[0066] FIGS. 2B and 2C show examples of layers of hard materials which may be disposed at one or more locations 101*a*-105*a* in accordance with teachings of the present disclosure. FIG. 2B shows first layer or sublayer 111, second layer or sublayer 112 and third layer or sublayer 113 disposed at location 101*a* in mold assembly 200. The resulting configuration of layers or sublayers 111, 112 and 113 may sometimes be referred to as "composite layer" 101. Each sublayer 111, 112 and 113 may have approximately the same general configuration and dimensions including thickness. Each layer 111, 112 and 113 may include a plurality of large pellets 130 and/or 140. Also, a plurality of smaller pellets and matrix material 131 used to form associated matrix drill bit 20 may also be disposed within layers 111, 112 and/or 113.

[0067] For embodiments such as shown in FIG. 2B, first layer 111 may start with a layer of glue disposed at location 101*a*. Various types of glue and/or adhesive materials including, but not limited to, aerosol adhesives such as Super 77 Multipurpose Adhesive available from 3M Company located in St. Paul, Minn. may be satisfactorily used. Hard particles or hard pellets 130 as shown in FIGS. 2B and 3C and/or hard pellets 140 as shown in FIGS. 4B and 4C may then be disbursed within the glue of first layer 111. Matrix material 131 may also be disbursed within first layer 111. The ratio of hard pellets or hard particles with respect to matrix material may be selected to provide desired uniformity of the resulting first layer 111 and desired hardness.

[0068] A second layer of glue may be disposed on first layer 110 at location 101*a*. Additional hard pellets 130 and/or 140 may then be distributed within the glue at second layer 112. Matrix material 131 may be disbursed within the glue at second layer 112. Similar procedures may be used to form third layer 113 and additional layers of glue, hard pellets and/or matrix material as desired for each selected location on exterior portions of matrix drill bit 20.

[0069] The dimensions and configuration of each layer of glue may be selected to correspond with desired dimensions and configuration of corresponding layers 101-105 of hard material disposed at selected locations on exterior portions of matrix drill bit 20. For some applications, the total thickness of the hard material disposed at respective locations 101*a*-105*a* may be between approximately 0.25 inches and 0.5 inches.

[0070] FIG. 2C is a schematic drawing showing single layer 114 and hard materials which may also be disposed at location 101*a* or any other desired location in mold assembly 200. The overall configuration and dimensions of layer 114 in FIG. 2C may be approximately the same as composite layer 101 in FIG. 2B. For some applications, pellets 130 and/or 140 as shown in FIG. 2C may be larger than corresponding pellets 130 and/or 140 as shown in FIG. 2B. For some applications increasing the size of the pellets may accommodate forming layer 114 in FIG. 2C in a "single pass" of adhesive material and a "single pass" to disperse hard materials therein as compared with composite layer 101 formed by using three separate layers or sublayers 111, 112 and 113 of glue and respective distribution of hard materials within each layer or sublayer.

[0071] The types of hard materials used to form layers 111, 112, 113 and 114 may be selected to be compatible with infiltration of binder material therethrough during infiltration of matrix materials 131 and 132 to form matrix bit body 50. Some examples of hard materials which may be satisfactory used to form one or more layers of hard material disposed on exterior portions of a matrix drill bit in accordance with teachings of the present disclosure are shown in FIGS. 3B, 3C, 4B and 4D.

[0072] FIGS. 3C and 4C are schematic representations of respective layers of hard material disposed on matrix material 131 in accordance with teachings of the present disclosure. For purposes of explanation, surface 122 as shown in FIGS. 3C and 4C may be representative of respective exterior surfaces 122 associated with layers 101-105 of hard material disposed at selected locations on exterior portions of matrix drill bit 50. See FIG. 1. Respective surfaces 122 of layers 101-105 may conform with and be tightly bonded to adjacent matrix materials used to form matrix bit body 50. The cross sections of a layer of hard material disposed on matrix material as shown in FIGS. 3C and 4C may also be representative of one or more layers of hard material disposed in recesses 70 to form a gage pad (not expressly shown) on respective blades 54.

[0073] Layer 103 as shown in FIG. 3C may include tungsten carbide particles or pellets 130 disposed in matrix 146 in accordance with teachings of the present disclosure. Other hard materials and/or hard particles selected from a wide variety of metals, metal alloys, ceramic alloys and/or cermets may also be used to form one or more layers 103 of hard material. As a result of using tungsten carbide particles 130 having an optimum weight percentage of binder material, layer 103 may enhance erosion, abrasion, wear, impact and/or fatigue resistance as compared with exterior portions of matrix bit body 50 which do not include such layers of hard material.

[0074] Layer 104 as shown in FIG. 4C may include tungsten carbide particles or pellets 130 and encapsulated diamond particles 140. In accordance with teachings of the present disclosure. Other hard materials and/or hard particles selected from a wide variety of metals, metal alloys, ceramic alloys and/or cermets may also be used to form one or more layers 104 of hard material. By including both a combination of tungsten carbide pellets 130 and diamond encrusted particles or pellets 140, layer 104 may have enhanced erosion, abrasion, wear, impact and/or fatigues resistance as compared with exterior portions of matrix bit body **50** which do not include such layers of hard material.

[0075] FIGS. **3**A and **4**A shows examples of welding rods which may be satisfactory used to form one or more layers of hard material on exterior portions of matrix bit body **50** such as respective recesses **70** formed on blades **54** following removal of matrix bit body **50** from as associated mold assembly. The welding rods **71** and **71***a* may also be used to form one or more layers of hard material to repair a used matrix drill bit in accordance with teachings of the present disclosure.

[0076] For some applications both new matrix bit bodies and used matrix drill bits may be heated to a desired temperature such as approximately seven hundred degrees Fahrenheit (700° F.) and allowed to "soak" prior to forming one or more layers of hard material on exterior portions thereof using welding rods **71** or **71***a*. The desired temperature may vary depending on materials used to form an associated matrix bit body and hard particles used to form the layers of hard material.

[0077] Heating a matrix bit body to an appropriate, relatively uniform temperature may minimize potential cracking or damage to the matrix bit body during welding. After one or more layers of hard material have been disposed at selected locations on the associated matrix bit body, the matrix bit body may be slowly cooled at a desired rate to ambient temperature. The cooling rate may be selected to prevent cracking or damage to the matrix bit body and/or layers of hard material.

[0078] Welding rod **71** as shown in FIGS. **3**A and **3**B may be used to form a layer of hard material with characteristics similar to layer **103** as shown in FIG. **3**C. Welding rod **71***a* as shown in FIGS. **4**A and **4**B may be used to form a layer of hard material with characteristics similar to layer **104***a* shown in FIG. **4**C. Welding rods **71** and **71***a* may include respective hollow steel tube **76** which may be closed at both ends with filler **78** and hard particles **130** and/or **140** or other hard materials disposed therein.

[0079] For some applications tungsten carbide pellets may have generally spherical configurations (see FIGS. **3**C and **4**C) with a weight percentage of binder between approximately four percent (4%) plus or minus one percent (1%) of the total weight of each tungsten carbide pellet in accordance with teachings of the present disclosure. Tungsten carbide pellets may also be formed with an optimum weight percentage of binder and various non-spherical or partially spherical configurations (not expressly shown). For some applications crushed tungsten carbide pellets may also be used.

[0080] Spherical tungsten carbide pellets formed with no binding material or substantially 0% binder may tend to crack and/or fracture during formation of a matrix deposit or hardfacing layer containing such pellets. Tungsten carbide pellets formed with no binding material or substantially 0% binder may also fracture or crack when exposed to thermal stress and/or impact stress. Spherical tungsten carbide pellets formed with relatively high percentages (5% or greater) by weight of binding material or binder may tend to break down or dissolve into solution during formation of an associated matrix deposit or hardfacing layer. As a result, such spherical tungsten carbide pellets and associated matrix deposit or hardfacing layer may have less abrasion, erosion, wear, impact, and/or fatigue resistance than desired. Spherical tungsten carbide pellets with more than 5% binder may crack when exposed to thermal stress and/or impact stress.

[0081] Tungsten carbide pellets formed with an optimum percentage of binding material or binder may neither crack nor dissolve into solution in associated matrix material during formation of one or more layers of hard material. Spherical tungsten carbide pellets formed with an optimum percentage of binding material and/or binder may also neither crack nor fracture when exposed to thermal stress and/or impact stress. Forming tungsten carbide pellets with an optimum weight percentage of binding material in accordance with teachings of the present disclosure may improve weldability of the tungsten carbide pellets and may substantially improve temperature stress resistance and/or impact stress resistance of the tungsten carbide pellets to fracturing and/or cracking.

[0082] For some applications layers of hard material formed with spherical tungsten carbide particles having an optimum weight percentage of binder have shown improved wear properties during testing of associated layers and/or matrix deposits. For some applications improvement in wear properties may increase approximately forty-five percent (45%) during wear testing in accordance with ASTM B611 as compared with a matrix deposits or layers of hard material having spherical tungsten carbide particles with binding material representing five percent (5%) or greater the total weight of each tungsten carbide particle.

[0083] Layers of hard material may be formed with tungsten carbide pellets having an optimum weight percentage of binding material in a wide range of mesh sizes. For some applications the size of such tungsten carbide pellets may vary between approximately 12 U.S. mesh and 100 U.S. mesh. The ability to use a wide range of mesh sizes may substantially reduce costs of manufacturing such tungsten carbide pellets and costs associated with forming a deposit matrix or hardfacing with such tungsten carbide pellets. For example, tungsten carbide pellets **130** as shown in FIG. **3**C or **4**C may have a size range from approximately 12 to 100 U.S. Mesh.

[0084] Depending upon selected locations for depositing one or more layers of hard material on a matrix bit body, tungsten carbide pellets **130** may be selected within a more limited size range such as 40 U.S. Mesh to 80 U.S. Mesh. For other applications, tungsten carbide pellets **130** may be selected from two or more different size ranges such as 30 to 60 mesh and 80 to 100 mesh. Tungsten carbide pellets **130** may have approximately the same general spherical configuration. However, by including tungsten carbide pellets **130** or other hard particles with different configurations and/or mesh ranges, wear, erosion, abrasion, impact, and/or fatigue resistance of resulting layers of hard material may be modified to accommodate specific downhole operating environments for an associated matrix drill bit. By increasing the size of tungsten carbide pellets **130**, a single layer of hard material having optimum thickness may be deposited within mold assembly **200** with a single pass. For some applications the optimum size for tungsten carbide pellets may be approximately sixteen (16) mesh to thirty (30) mesh.

[0085] Tungsten carbide pellets may be formed by cementing, sintering, and/or HIP-sintering (sometimes referred to as "sinter-hipping") fine grains of tungsten carbide with an optimum weight percentage of binding material. Sintered tungsten carbide pellets may be made from a mixture of tungsten carbide and binding material such as cobalt powder. Other examples of binding materials include, but are not limited to cobalt, nickel, boron, molybdenum, niobium, chromium, iron, and alloys of these elements. Various alloys of such binding materials may also be used to form tungsten carbide pellets in accordance with teachings of the present disclosure. The weight percentage of the binding material may be approximately four percent (4%) plus or minus one percent (1%) of the total weight of each tungsten carbide pellet.

[0086] A mixture of tungsten carbide and binding material may be used to form green pellets. The green pellets may then be sintered or HIP-sintered at temperatures near the melting point of cobalt to form either sintered or HIP-sintered tungsten carbide pellets with an optimum weight percentage of binding material. HIP-sintering may sometimes be referred to as "over pressure sintering" or as "sinter-hipping."

[0087] Sintering a green pellet generally includes heating the green pellet to a desired temperature at approximately atmospheric pressure in a furnace with no force or pressure applied to the green pellet. HIP-sintering a green pellet generally includes heating the green pellet to a desired temperature in a vacuum furnace with pressure or force applied to the green pellet.

[0088] A hot isostatic press (HIP) sintering vacuum furnace generally uses higher pressures and lower temperatures as compared to a conventional sintering vacuum furnace. For example, a sinter-HIP vacuum furnace may operate at approximately 1400° C. with a pressure or force of approximately 800 µsi applied to one or more hot tungsten carbide pellets. Construction and operation of sinter-HIP vacuum furnaces are well known. The melting point of binding material used to form tungsten carbide pellets may generally decrease with increased pressure. Furnaces associated with sintering and HIP-sintering are typically able to finely control temperature during formation of tungsten carbide pellets.

[0089] Layers of hard material disposed at selected locations on exterior portions of a matrix body may include tungsten carbide particles or pellets **130** having an optimum weight percentage of binding material in accordance with teachings of the present disclosure. Other hard materials and/or hard particles selected from a wide variety of metals, metal alloys, ceramic alloys, and cermets may be used to form layers **101-105** of hard material. As a result of using tungsten carbide particles **130** having an optimum weight percentage of binding material, layers **101-105** of hard material may have significantly enhanced abrasion, erosion, wear, impact, and/or fatigue resistance.

[0090] A plurality of tungsten carbide pellets **130** having an optimum weight percentage of binding material in accordance with teachings of the present disclosure may be dispersed within filler **78**. A plurality of coated diamond particles **140** may also be dispersed within filler **78** of welding rod **71***a*. Conventional tungsten carbide particles or pellets (not expressly shown) which do not have an optimum weight percentage of binder material may sometimes be included as part of filler **78**. For some applications, filler **78** may include a deoxidizer and a temporary resin binder. Examples of deoxidizers satisfactory for use with the present disclosure may include various alloys of iron, manganese, and silicon.

[0091] For some applications, the weight of welding rods **71** and/or **71***a* may be approximately fifty-five percent to eighty percent filler **78** and twenty to thirty percent or more steel tube **76**. Layers of hard material formed by welding rods with less than approximately fifty-five percent by weight of filler **78** may not provide sufficient wear resistance. Welding rods with more than approximately eighty percent by weight of filler **78** may be difficult to use to form layers of hard material with desired dimensions including thickness and/or desired configurations.

[0092] Loose material such as powders of hard material selected from the group consisting of tungsten, niobium, vanadium, molybdenum, silicon, titanium, tantalum, zirconium, chromium, yttrium, boron, carbon and carbides, nitrides, oxides, or silicides of these materials may be included as part of filler **78**. The loose material may also include a powdered mixture selected from the group consisting of copper, nickel, iron, cobalt, and alloys of these elements to form matrix bit body **50**. Powders of materials selected from the group consisting of metal borides, metal carbides, metal oxides, metal nitrides, and other superhard or superabrasive alloys may be included within filler **78**. The specific compounds and elements selected for filler **78** will generally depend upon intended applications for the resulting matrix drill bit and selected welding technique.

[0093] When tungsten carbide pellets **130** are mixed with other hard particles, such as coated diamond particles **140**, both types of hard particles may have approximately the same density. One of the technical benefits of the present disclosure may include varying the percentage of binding materials associated with tungsten carbide pellets **130** and thus the density of tungsten carbide pellets **130** to ensure compatibility with coated diamond particles **140** and/or matrix portion **146** of layers **101-105** of hard material.

[0094] Tungsten carbide pellets **130** with or without coated diamond particles **140** and selected loose materials may be included as part of a continuous welding rod (not expressly shown), composite welding rod (not expressly shown), core wire (not expressly shown) and/or welding rope (not expressly shown). For some applications flexible, hard facing ropes may be satisfactorily used to form one or more layers of hard material at selected locations on exterior portions of a new matrix drill bit or a used (dull) matrix drill bit. Flexible welding rope or hard facing rope may be available from several vendors including, but not limited to, Technogenia, Inc. having offices in Conroe, Tex. and Atlanta, Ga. Some welding ropes may include a central small diameter nickel wire coated with a thick layer of hard particles and matrix material such shown in FIGS. **3**B and **4**B.

[0095] Oxyacetylene welding, atomic hydrogen welding techniques, tungsten inert gas (TIG-GTA), stick welding, SMAW and/or GMAW welding techniques may be satisfactorily used to form layers of hard material at selected locations on used matrix drill bit or new matrix bit bodies using welding rods, welding rope, etc.

[0096] For some applications, a mixture of tungsten carbide pellets **130** and coated diamond particles **140** may be blended and thermally sprayed onto select portions of a matrix body of a matrix body using techniques well known in the art. A laser may then be used to densify and fuse the resulting powdered mixture at selected locations on exterior portions of the matrix body. U.S. Pat. No. 4,781,770 entitled "A process For Laser Hardfacing Drill Bit Cones Having Hard Cutter Inserts" shows one process satisfactory for use with the present disclosure.

[0097] Layers of hard material **103** and **104** as shown in FIG. **3**C and FIG. **4**C may include a plurality of tungsten carbide particles **130** embedded or encapsulated in matrix portions **146** and **146***a*. Various materials including cobalt, copper, nickel, iron, and alloys of these elements may be used to form matrix portions **146** and **146***a*. For some applications matrix portions **146** and **146***a* may be similar to and operable to bond with adjacent portion of matrix **131**.

[0098] Coated diamond particles or encrusted diamond particles **140** may be formed using various techniques such as those described in U.S. Pat. No. 4,770,907 entitled "Method for Forming Metal-Coated Abrasive Grain Granules" and U.S. Pat. No. 5,405,573 entitled "Diamond Pellets and Saw Blade Segments Made Therewith."

[0099] Coated diamond particles **140** may include diamond **144** with coating **142** disposed thereon. Materials used to form coating **142** may be metallurgically and chemically compatible with materials used to form both matrix portion **146***a* and binder for tungsten carbide pellets **130**. For many applications, the same material or materials used to form coating **142** will also be used to form matrix portion **146***a* and associated matrix bit body.

[0100] Metallurgical bonds may be formed between coating **142** of each coated diamond particle **140** and matrix portion **146***a*. As a result of such metallurgical or chemical bonds coated diamond particles **140** may remain fixed within layers of hard material **101-105** until the adjacent tungsten carbide pellets **130** and/or other hard materials in matrix portion **146***a* have been worn away. Coated diamond particles **140** may provide high levels of abrasion, erosion and wear resistance to protect an associated matrix body as compared with hardfacing formed from only matrix portion **146***a* and tungsten carbide pellets **130**. High abrasion, erosion, wear, impact, and/or fatigue resistance of the newly exposed tungsten carbide pellets **130** and/or coated diamond particles **140** may increase overall abrasion, erosion, wear, impact, and/or fatigue resistance of layers of hard material **101-105**. As surrounding matrix portion **146***a* continues to be worn away, additional tungsten carbide pellets **130** and/or coated diamond particles **140** may be exposed to provide continued protection and increased useful life of an associated matrix drill bit.

[0101] Additional information about coated or encrusted diamond particles and other hard particles may be found in U.S. Pat. No. 6,469,278 entitled "Hardfacing Having Coated Ceramic Particles Or Coated Particles Of Other Hard Materials;" U.S. Pat. No. 6,170,583 entitled "Inserts And Compacts Having Coated Or Encrusted Cubic Boron Nitride Particles;" U.S. Pat. No. 6,138,779 entitled "Hardfacing Having Coated Ceramic Particles Or Coated Particles Of Other Hard Materials Placed On A Rotary Cone Cutter" and U.S. Pat. No. 6,102,140 entitled "Inserts And Compacts Having Coated Or Encrusted Diamond Particles."

[0102] The ratio of coated diamond particles **140** or other hard particles with respect to tungsten carbide pellets **130** disposed within layers of hard material **101-105** may be varied to provide desired erosion, abrasion, wear, impact, and fatigue resistance for an associated matrix bit body depending upon anticipated downhole operating environment. For some extremely harsh environments, the ratio of coated diamond particles **140** to tungsten carbide particles **130** may be 10:1. For other downhole drilling environments, the ratio may be substantially reversed.

[0103] Tube rod welding with an oxyacetylene torch (not shown) may be satisfactorily used to form metallurgical bonds between layers of hard material and adjacent portions of matrix bit body **50** and metallurgical and/or mechanical bonds between matrix portion **146** and tungsten carbide pellets **130**. For other applications, laser welding techniques may be used to form layers of hard material on exterior portions of a matrix body.

[0104] Mold assembly **200***a* as shown in FIG. **5** may include several components such as mold **203***a*, gauge ring or connector ring **204***a*, and funnel **220***a*. Mold **203***a*, gauge ring **204***a*, and funnel **220***a* may be formed from graphite or other suitable materials. Various techniques may be used including, but not limited to, machining a graphite blank to form mold cavity **252***a* having a negative profile or a reverse profile of desired exterior features for a resulting fixed cutter drill bit. For example mold cavity **204***a* may have a negative profile which corresponds with the exterior profile or configuration of blades **54** and junk slots **56** as shown in FIG. **1**.

[0105] Various types of temporary displacement materials and mold insert may be satisfactorily installed within mold cavity **252***a* depending on the desired configuration of a resulting matrix drill bit. For example mold inserts **70***a* may be formed from various materials such as consolidated sand and/or graphite may be disposed within mold cavity **104**. Various resins may be satisfactorily used to form consolidated sand. Mold inserts **70***a* may have configurations and dimensions corresponding with desired features of matrix bit body **50** such as recess **70** formed in exterior portion **58** of blades **54**. The dimensions and configuration of mold inserts **70***a* and associated recesses **70** may be selected to correspond with desired dimensions and configuration for resulting gage pads (not expressly shown) on respective blades **54**.

[0106] Matrix bit body **50** may include relatively large fluid cavity or chamber **32** with multiple fluid flow passageways **72** and **74** extending therefrom. See FIG. **6**. As shown in FIG. **5**, displacement materials such as consolidated sand may be installed within mold assembly **200***a* at desired locations to form portions of cavity **32** and fluid flow passages **72** and **74** extending therefrom. The orientation and configuration of consolidated sand legs **172** and **174** may be selected to correspond with desired locations and configurations of associated fluid flow passageways **72** and **74** communicating from cavity **32** to respective nozzles **68**.

[0107] A relatively large, generally cylindrically shaped consolidated sand core **150** may be placed on the legs **172** and **174**. The number of legs extending from sand core **150** will depend upon the desired number of nozzle openings in a resulting matrix bit body.

[0108] After desired displacement materials, including core **150** and legs **172** and **174**, have been installed within mold assembly **200***a*, matrix material **131** having desired characteristics for matrix bit body **50** may be placed within mold assembly **200***a*. The present disclosure allows the use of matrix materials having characteristics of toughness and wear resistance for forming a fix cutter drill bit or drag bit.

[0109] A generally hollow, cylindrical bit blank **36** may then be placed within mold assembly **200***a*. Bit blank **36** preferably includes inside diameter **37** which is larger than the outside diameter of sand core **150**. Various fixtures (not expressly shown) may be used to position bit blank **36** within mold assembly **200***a* at a desired location spaced from first matrix material **131**.

[0110] For some applications second matrix material **132** such as tungsten powder may then be placed in mold assembly **200***a* between exterior portions of bit blank **36** and adjacent interior portions of funnel **220***a*. Second matrix material **132** may be a relatively soft powder which forms a matrix that may subsequently be machined to provide a desired exterior configuration and transition between matrix bit body **50** and bit blank **36**. See FIG. **6**. Second matrix material **132** may sometimes be described as an "infiltrated machinable powder."

[0111] Matrix material **131** may be cemented carbides and/or spherical carbides as previously discussed. Alloys of cobalt, iron, and/or nickel may be used to form cemented carbides and/or spherical carbides. For some matrix drill bit designs an alloy concentration of approximately six percent in the first matrix material may provide optimum results. Alloy concentrations between three percent and six percent and between approximately six percent and fifteen percent may also be satisfactory for some matrix drill bit designs. However, alloy concentrations greater than approximately fifteen percent and alloy concentrations less than approximately three percent may result in less than optimum characteristics of a resulting matrix bit body.

[0112] A typical infiltration process for forming matrix bit body **50** may begin by forming mold assembly **200***a*. Gage ring **204***a* may be threaded onto the top of mold **203***a*. Funnel **220***a* may be threaded onto the top of gage ring **204***a* to extend mold assembly **200***a* to a desired height to hold previously described matrix materials and binder material. Displacement materials such as, but not limited to, mold inserts **70***a*, legs **172** and **174**, and sand core **150** may then be loaded into mold assembly **200***a* if not previously placed in mold cavity **252***a*. Matrix materials **131** and **132** and bit blank **36** may be loaded into mold assembly **200***a* as previously described.

[0113] As mold assemblies **200** or **200***a* are being filled with matrix materials, a series of vibration cycles may be induced in each mold assembly **200** or **200***a* to assist desired distribution of each layer or zone of matrix materials **131** and **132**. Vibrations help to ensure consistent density of each layer of matrix materials **131** and **132** within respective ranges required to achieve desired characteristics for matrix bit body **50**.

[0114] Binder material **160** may be placed on top of layer **132**, bit blank **36** and core **150**. Binder material **160** may be covered with a flux layer (not expressly shown). A cover or lid (not expressly shown) may be placed over mold assembly **200***a*. Mold assembly **200***a* and materials disposed therein may be preheated and then placed in a furnace (not expressly shown). When the furnace temperature reaches the melting point of binder material **160**, liquid binder material **160** may infiltrate matrix materials **131** and **132** and layer **101**-**105** of hard material. See FIG. **2**A.

[0115] Mold assembly **200***a* may then be removed from the furnace and cooled at a controlled rate. Once cooled, mold assembly **200***a* may be broken away to expose matrix bit body **50**. See for example FIG. **6**.

[0116] Although the present disclosure has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present disclosure encompass such changes and modifications as fall within the scope of the present appended claims.

1-22. (canceled)

24. A method of making a matrix drill bit comprising:

determining potential locations for excessive erosion, abrasion and/or wear of exterior portions of a matrix bit body;

placing layers of hard material at selected locations on interior portions of a matrix bit body mold corresponding with the potential locations for excessive erosion, abrasion and/or wear of exterior portions of the associated matrix bit body;

placing a hollow bit blank in the matrix bit body mold;

placing at least one matrix material selected from the group consisting of cemented carbides, composite carbides, spherical carbides, macrocrystalline tungsten carbide and cast carbide and formulates thereof in the mold;

placing a binder material in the mold with the binder material disposed proximate the matrix material and the hollow bit blank;

heating the mold and the materials disposed therein to a selected temperature to allow the binder material to melt and infiltrate the matrix material and the layers of hard material and associated tungsten carbide pellets with hot, liquid binder material; and

cooling the mold and materials disposed therein to form a matrix bit body with multiple layers of hard material disposed proximate selected locations on exterior portions of the matrix bit body.

24. The method of claim **23** further comprising forming interior portions of the matrix bit body with more than one matrix material.

25. The method of claim **23** further comprising forming multiple layers of tungsten carbide pellets at selected locations on exterior portions of the matrix bit body associated with engaging and removing downhole formation materials during formation of a wellbore.

26. The method of claim **23** further comprising forming multiple layers of crushed sintered tungsten carbide at selected locations on exterior portions of the matrix bit body associated with engaging and removing downhole formation materials during formation of a wellbore.

27. (canceled)

28. The method of claim **23** further comprising forming the layers of the hard material with respective dimensions including thickness selected to minimize erosion, abrasion and/or wear proximate the corresponding selected location on exterior portions of the matrix bit body.

29. A method of making a matrix drill bit comprising:

determining potential locations for excessive erosion, abrasion and/or wear of exterior portions of a matrix bit body;

placing first layers of adhesive material at selected locations on interior portions of a matrix bit body mold corresponding with the potential locations for excessive erosion, abrasion and/or wear of exterior portions of a matrix bit body;

placing tungsten carbide pellets in each first layer of adhesive material;

placing a respective second layer of adhesive material on each first layer of adhesive material and associated tungsten carbide pellets;

placing additional tungsten carbide pellets in each second layer of adhesive material;

placing a hollow bit blank in the matrix bit body mold;

placing at least one matrix material selected from the group consisting of cemented carbides, composite carbides, spherical carbides, macrocrystalline tungsten carbide and cast carbide and formulates thereof in the mold;

placing a binder material in the mold with the binder material disposed proximate the matrix material and the hollow bit blank;

heating the mold and the materials disposed therein to a selected temperature to allow the binder material to melt and infiltrate the matrix material and the layers of adhesive material and associated tungsten carbide pellets with hot, liquid binder material; and

cooling the mold and materials disposed therein to form a matrix bit body with multiple layers of tungsten carbide pellets disposed proximate selected locations on exterior portions of the matrix bit body.

30. The method of claim **29** further comprising forming interior portions of the matrix bit body with more than one matrix material.

31. The method of claim **29** further comprising forming multiple layers of tungsten carbide pellets at selected locations on exterior portions of the matrix bit body associated with engaging and removing downhole formation materials during formation of a wellbore.

32. (canceled)

33. The method of claim **29** further comprising selecting the adhesive material from the group consisting of one component adhesives and two component adhesives.

34. The method of claim **29** further comprising forming the layers of second material with respective dimensions including thickness selected to minimize erosion, abrasion and/or wear proximate the corresponding selected location on exterior portions of the matrix bit body.

35. The method of claim **29** further comprising:

forming the mold cavity with a plurality of displacements disposed therein and each displacement having a complex, arcuate configuration corresponding with a desired configuration for a respective fluid flow path disposed on exterior portions of the a head; and

forming the mold cavity with a plurality of negative blade profiles with each negative blade profile disposed between associated displacements and each negative blade profile having a complex, arcuate configuration corresponding with a desired configuration for a respective blade disposed on exterior portions of the bit head.

36. The method of claim **29** further comprising selecting an infiltration material from the group consisting of tungsten carbide, monotungsten carbide, ditungsten carbide, macro crystalline tungsten carbide, other metal carbides, metal borides, metal oxides, metal nitrides, polycrystalline diamond (PCD) or mixtures of such infiltration materials.

37-55. (canceled)

56. The method of claim **24**, wherein determining comprises simulating fluid flow over exterior portions of the matrix drill bit in combination with analyzing wear patterns on exterior portions of a similar used matrix drill bit.

57. The method of claim **56**, wherein simulating fluid flow comprises using a computational fluid dynamics program.

58. The method of claim **56**, wherein analyzing wear patterns comprises three dimensional (3D) scanning of the similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

59. The method of claim **58**, wherein 3D scanning comprises digital scanning.

60. The method of claim **56**, wherein analyzing wear patterns comprises visual inspection of the similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

61. The method of claim **24**, wherein determining comprises three dimensional (3D) scanning of a similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

62. The method of claim **61**, wherein 3D scanning comprises digital scanning.

63. The method of claim **24**, wherein determining comprises visual inspection of a similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

64. The method of claim **29**, wherein determining comprises simulating fluid flow over exterior portions of the matrix drill bit in combination with analyzing wear patterns on exterior portions of a similar used matrix drill bit.

65. The method of claim **64**, wherein simulating fluid flow comprises using a computational fluid dynamics program.

66. The method of claim **64**, wherein analyzing wear patterns comprises three dimensional (3D) scanning of the similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

67. The method of claim **66**, wherein 3D scanning comprises digital scanning.

68. The method of claim **64**, wherein analyzing wear patterns comprises visual inspection of the similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

69. The method of claim **29**, wherein determining comprises three dimensional (3D) scanning of a similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

70. The method of claim **69**, wherein 3D scanning comprises digital scanning.

71. The method of claim **29**, wherein determining comprises visual inspection of a similar used matrix drill bit to determine areas of excessive erosion, abrasion and/or wear of exterior portions of the used matrix bit body.

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