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(54) **MANUFACTURING PROCESS FOR MATRIX DRILL BITS**

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CPC ***B22D 19/06*** (2013.01); ***B22D 19/02*** (2013.01)

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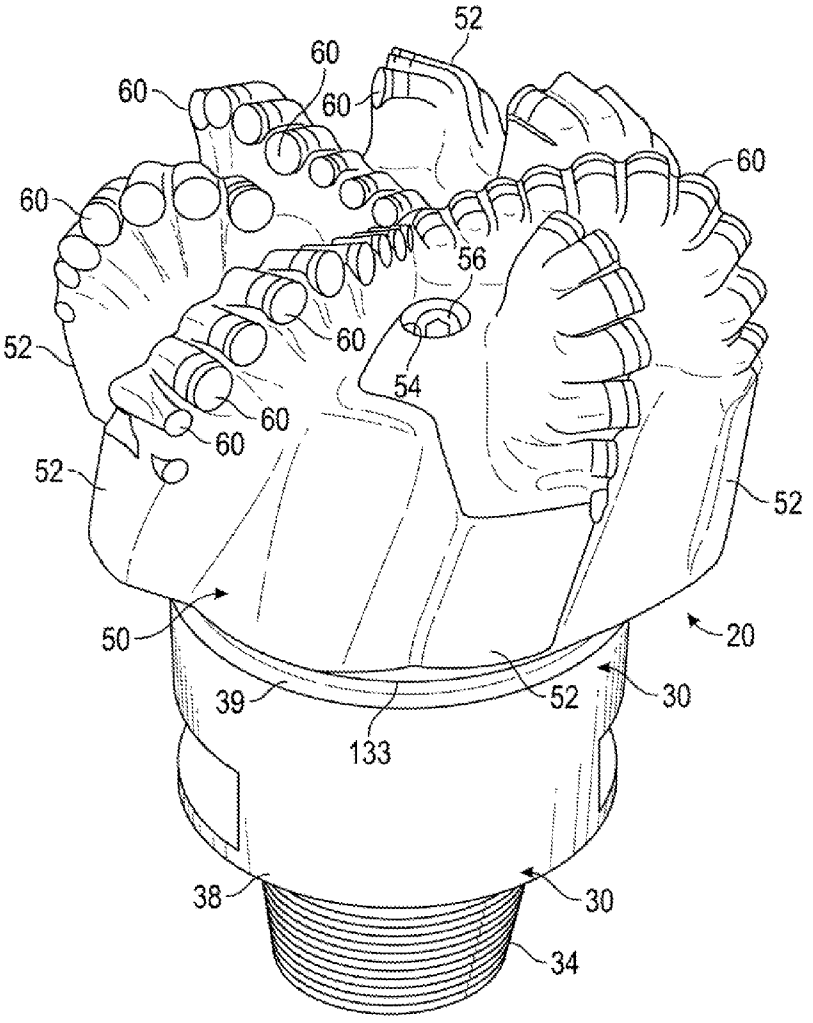
(57) **ABSTRACT**

A process for reducing inclusions during manufacturing of a matrix drill bit comprises placing at least a first layer of a first matrix material in a matrix bit body mold. At least a second layer of a second matrix material is placed in the mold. A binder material is placed in the mold with the binder material disposed proximate the second layer of matrix material and a metal a blank. A graphite lid is placed on the mold. The mold and the materials disposed therein are heated to a selected temperature to cause the binder material to melt and to allow the hot, liquid binder material to infiltrate the second matrix material and the first matrix material, with the second matrix material operable to improve infiltration of the first matrix material by the hot, liquid binder material without using a flux material.



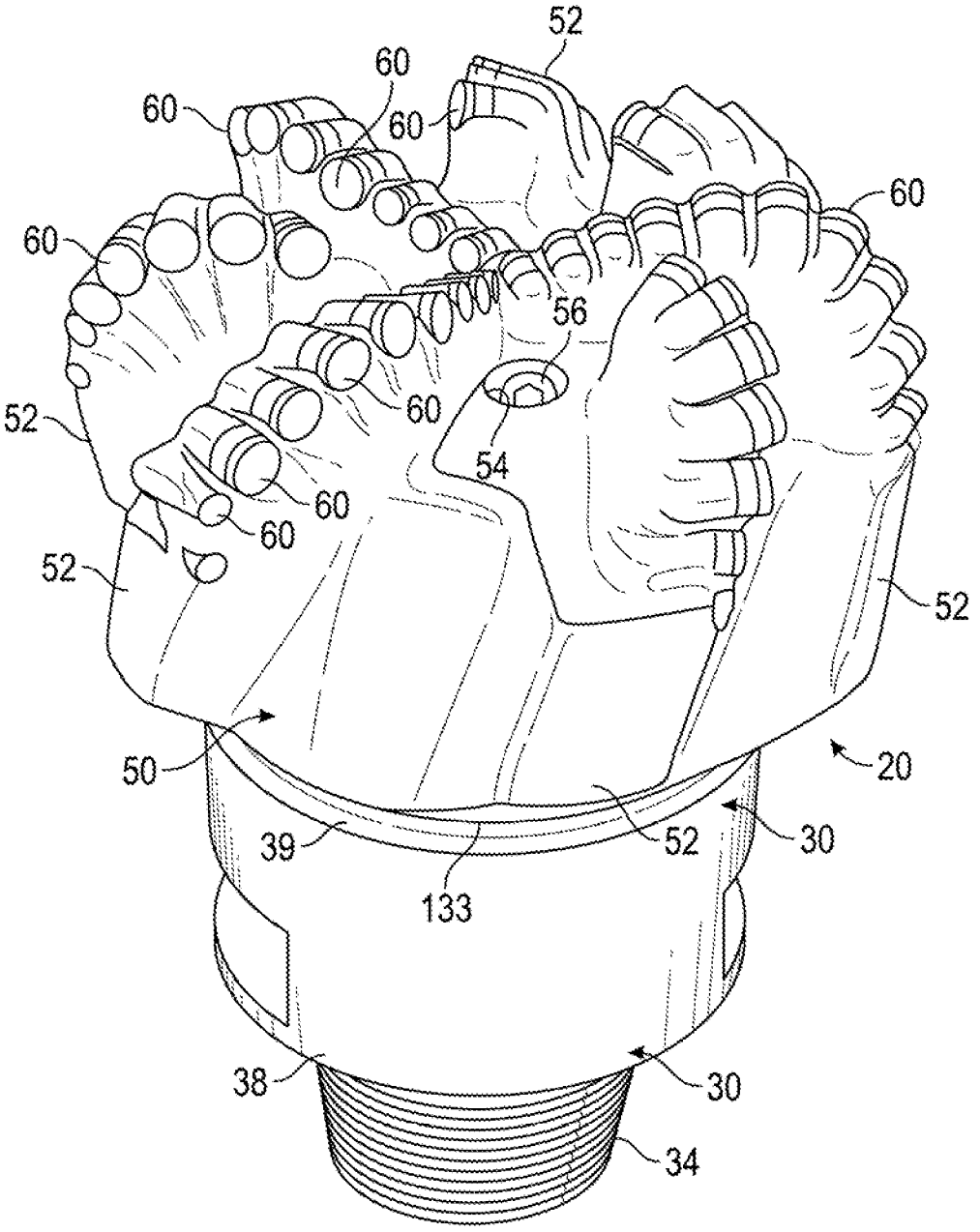
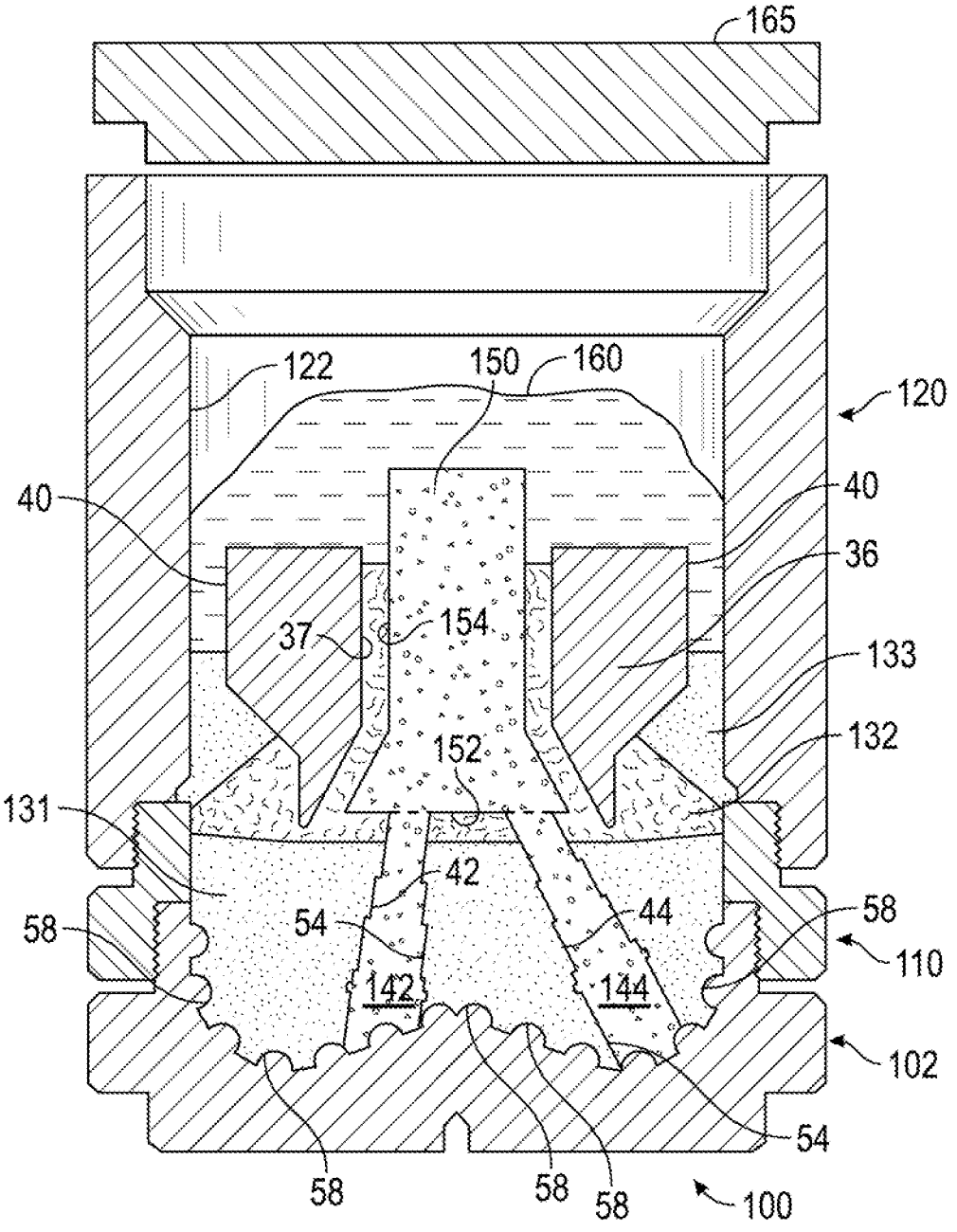


FIG. 1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110
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100

FIG. 2

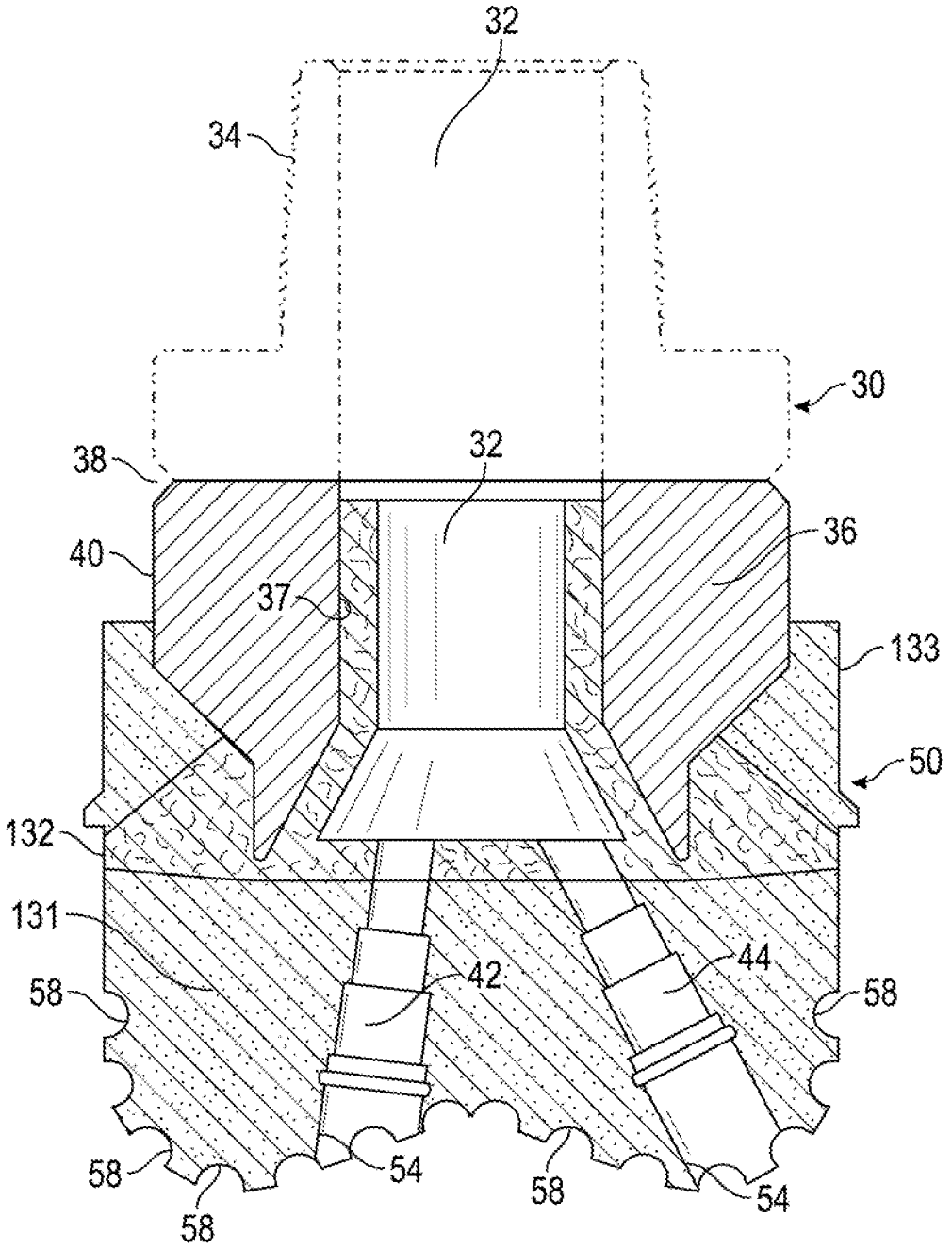


FIG. 3

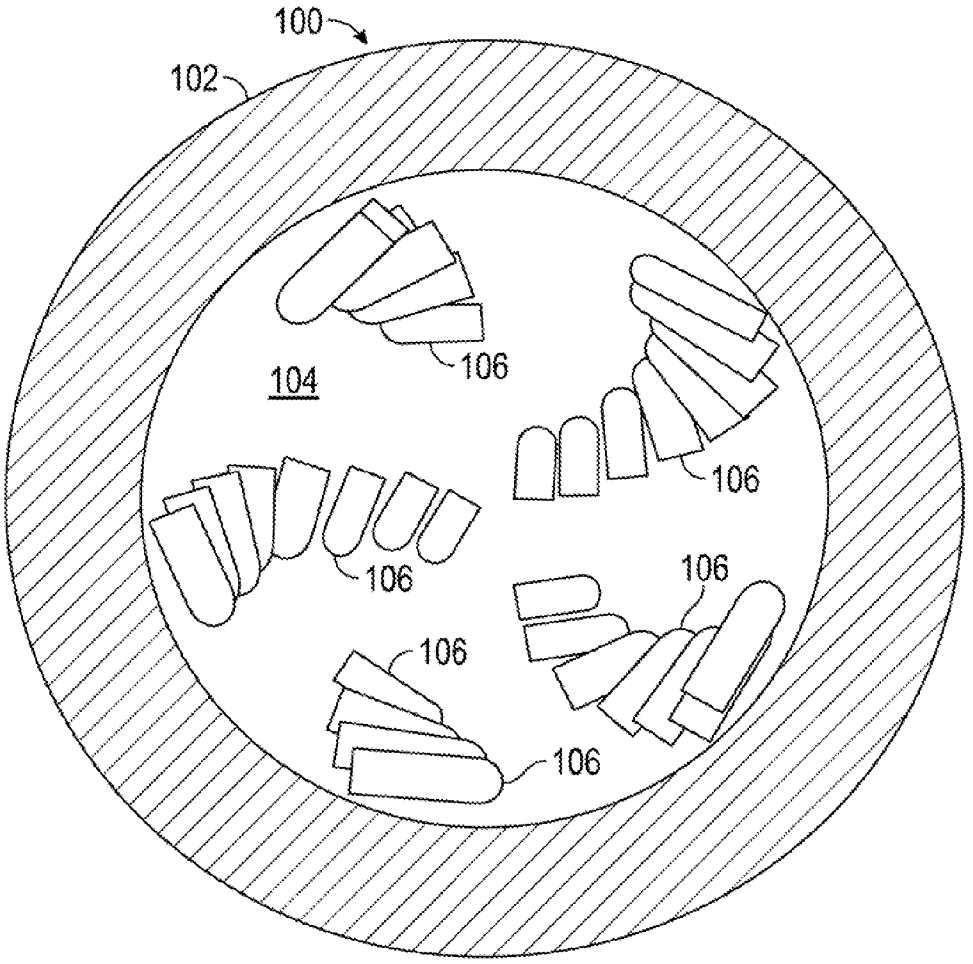


FIG. 4

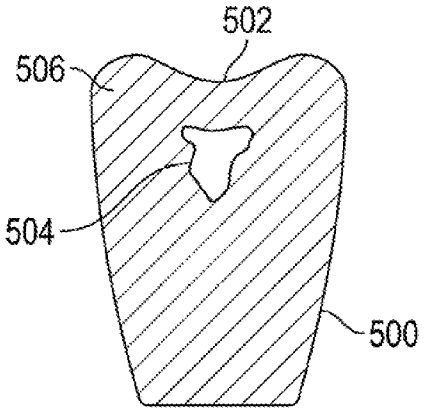


FIG. 5A

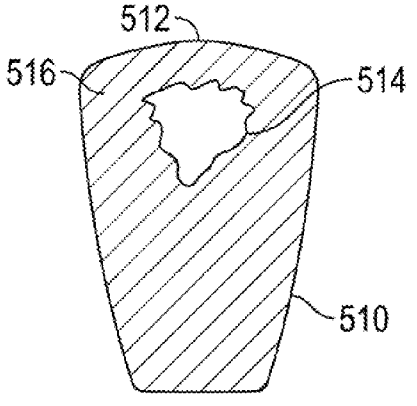
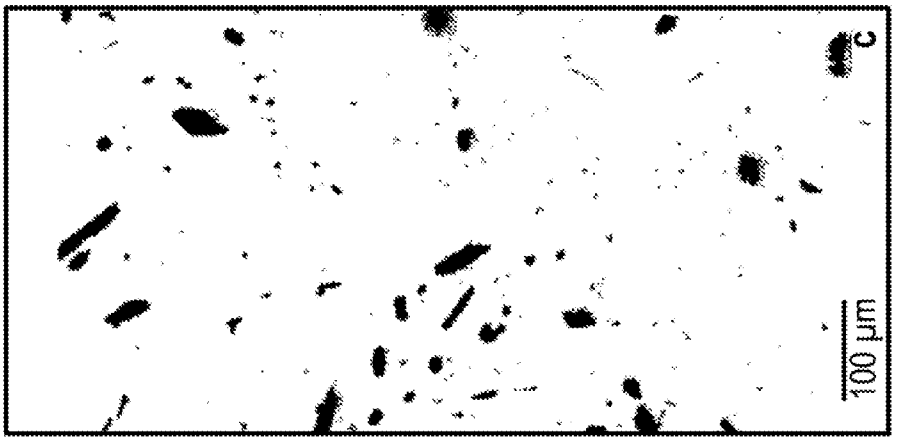
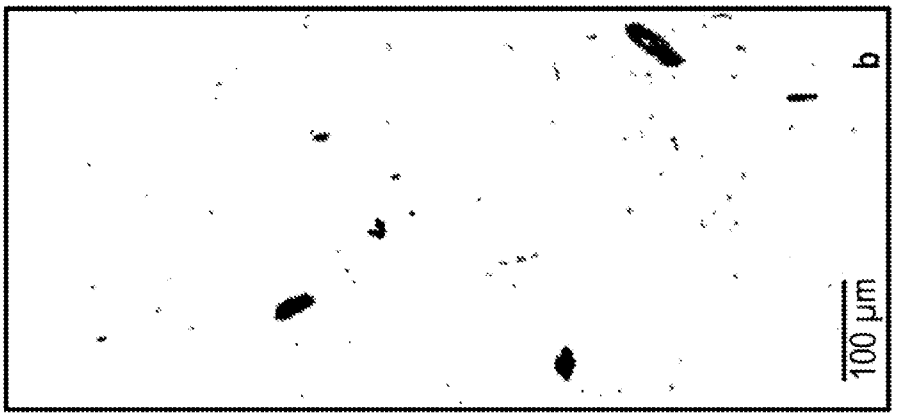


FIG. 5B



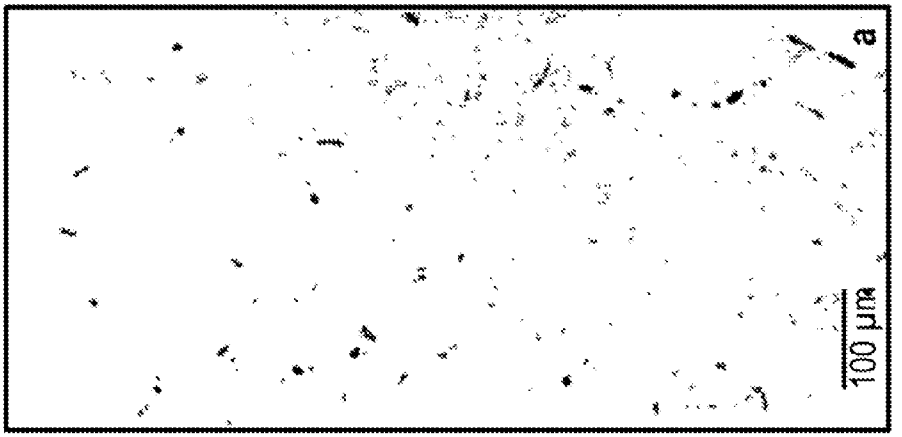
4 wt % Flux

FIG. 6C



2 wt % Flux

FIG. 6B



0% Flux

FIG. 6A

MANUFACTURING PROCESS FOR MATRIX DRILL BITS

TECHNICAL FIELD

[0001] The present invention is related to rotary drill bits and more particularly to matrix drill bits having a composite matrix bit body.

BACKGROUND OF THE INVENTION

[0002] Rotary drill hits 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 drilling equipment, or drag bits. Fixed cutter drill bits or drag bits are often 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 hits may sometimes be referred to as "matrix drill bits."

[0003] 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 binder such as a copper alloy. it is common practice to place a flux material over the infiltrant binder to help remove gases such as oxygen or hydrogen or prevent their absorption into the molten material. However, some infiltration defects may be attributed to the use of flux, for example, nonmetallic inclusions, impurities, and oxidation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] A more complete and thorough understanding of the present embodiments and advantages thereof may be acquired by referring to the following description taken in conjunction with the accompanying drawings, in which like reference numbers indicate like features, and wherein:

[0005] FIG. **1** is a schematic drawing showing an isometric view of a fixed cutter drill bit having a matrix bit body formed in accordance with teachings of the present disclosure;

[0006] FIG. **2** is a schematic drawing in section with portions broken away showing one example of a mold assembly with a first matrix material and a second matrix material satisfactory for forming a matrix drill bit in accordance with teachings of the present disclosure;

[0007] FIG. **3** is a schematic drawing in section with portions broken away showing a matrix bit body removed from the mold of FIG. **2** after binder material has infiltrated the first matrix material and the second matrix material;

[0008] FIG. **4** is a schematic drawing in section showing interior portions of one example of a mold satisfactory for use in forming a matrix bit body in accordance with teachings of the present disclosure;

[0009] FIG. **5**A is a schematic drawing showing a cross sectioned example of a binder sample manufactured without flux;

[0010] FIG. **5**B is a schematic drawing showing a cross sectioned example of a hinder sample manufactured with flux; and

[0011] FIGS. **6**A-**6**C show the metallographic defects for binder test samples with increasing amounts of flux.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0012] The terms "matrix drill bit" and "matrix drill bits" may be used in this application to refer to "rotary drag bits", "drag bits", "fixed cutter drill bits" or any other drill hit incorporating teaching of the present disclosure. Such drill bits may be used to form well bores or boreholes in subterranean formations.

[0013] 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 binder such as a copper alloy. The mold may be formed by milling a block of material, such as graphite to define a mold cavity with features that correspond generally with desired exterior 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 and/or by positioning temporary displacement material within interior portions of the mold cavity. A preformed steel shank or bit blank may be placed within the mold cavity to provide reinforcement for the matrix bit body and to allow attachment of the resulting matrix drill bit with a drill string.

[0014] A quantity of matrix material typically in powder form may then be placed within the mold cavity. The matrix material may be infiltrated with a molten metal alloy or binder which will form a matrix bit body after solidification of the binder with the matrix material. Tungsten carbide powder is often used to form conventional matrix bit bodies. A flux material may be in contact with the melted material in an effort to minimize oxidation and remove non-metallic impurities in the liquid melt.

[0015] In one embodiment, matrix drill bits may comprise a matrix bit body formed in part by at least a first matrix material and a second matrix material. Such matrix drill bits may he described as having a composite matrix bit body since at least two different matrix materials with different performance characteristics may be used to form the hit body. As discussed later in more detail, more than two matrix materials may he used to form a matrix bit body.

[0016] For some applications the first matrix material may have increased toughness or high resistance to fracture and also provide desired erosion, abrasion and wear resistance. The second matrix material preferably has only a limited amount (if any) of alloy materials or other contaminates. 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.

[0017] Various types of binder materials may be used to infiltrate matrix materials 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 (In), silicon (Si), molybdenum (Mo), tungsten (W), boron (B) and phosphorous (P). The matrix bit body may he attached to a metal shank. A tool joint having, a threaded connection operable to releasably engage the associated matrix drill bit with a drill string, drill pipe, bottom hole assembly or downhole drilling motor may be attached to the metal shank.

[0018] 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 he 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

[0019] 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 provides 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.

[0020] The binder materials used to form cemented carbides may sometimes be referred to as "bonding materials" in this patent application to help distinguish between binder materials used to form cemented carbides and binder materials used to form a matrix drill bit.

[0021] As discussed later in more detail, metallic elements and/or their alloys in bonding materials associated with cemented carbides may "contaminate" hot, liquid (molten) infiltrants such as copper based alloys and other types of binder materials associated with forming matrix drill bits as the molten infiltrant travels through the cemented carbides prior to solidifying to form a desired matrix. This kind of "contamination" (enrichment of infiltrant with bonding material from cemented carbides) of a molten infiltrant may alter the solidus (temperature below which infiltrant is all solid) and liquid US temperature above which infiltrant is all liquid) of the infiltrant as it travels under the influence of capillary action through the cemented carbide. This phenomena may have an adverse effect on the wettability of the cemented carbides resulting in lack of satisfactory infiltration of the cemented carbides prior to solidifying to form the desired matrix.

[0022] Cast carbides may generally be described as having two phases, tungsten monocarbide and ditungsten carbide. Cast carbides often have characteristics such as hardness, wettability and response to contaminated hot, liquid binders which are different from cemented carbides or spherical carbides.

[0023] Macrocrystalline tungsten carbide may he generally described as relatively small particles (powders) of single crystals of monotungsten carbide with additions of cast carbide, Ni, Fe, Carbonyl of Fe, Ni, etc. Both. cemented carbides and macrocrystalline tungsten carbides are generally described as hard materials with high resistance to abrasion, erosion and wear. Macrocrystalline tungsten carbide may also have characteristics such as hardness, wettability and response to contaminated hot, liquid binders which are different from cemented carbides or spherical carbides.

[0024] The terms "binder" or "binder material" may be used in this application to include copper, cobalt, nickel, iron, any alloys of these elements or any other material satisfactory for use in forming a matrix drill bit. Such hinders generally provide desired ductility, toughness and thermal conductivity for an associated matrix drill bit. Other materials such as, but not limited to, tungsten carbide have previously been used as hinder materials to provide resistance to erosion, abrasion and wear of an associated matrix drill bit. Binder materials may cooperate with two or more different types of matrix materials to form composite matrix bit bodies with increased toughness and wear properties as compared to many conventional matrix bit bodies.

[0025] FIG. **1** is a schematic drawing showing one example of a matrix drill hit or fixed cutter drill bit formed with a composite matrix bit body. For embodiments such as shown in FIG. **1**, matrix drill bit **20** may include metal shank **30** with composite matrix bit body **50** securely attached thereto. Metal shank **30** may be described as having a generally hollow, cylindrical configuration defined in part by fluid flow passageway **32** in FIG. **3**. Various types of threaded connections, such as American Petroleum Institute (API) connection or threaded pin **34**, may be formed on metal shank **30** opposite from composite matrix bit body **50**.

[0026] For some applications, generally cylindrical metal blank or casting, blank **36** (See FIGS. **2** and **3**) may be attached to hollow, generally cylindrical metal shank **30** using various techniques. For example annular weld groove **38** (See FIG. **3**) may be formed between adjacent portions of blank **36** and shank **30**. Weld **39** may be formed in groove **38** between blank **36** and shank **30**. See FIG. **1**. Fluid flow passageway or longitudinal bore **32** preferably extends through metal shank **30** and metal blank **36**. Metal blank **36** and metal shank **30** may be formed from various steel alloys or any other metal alloy associated with manufacturing rotary drill bits.

[0027] A matrix drill bit may include a plurality of cutting elements, inserts, cutter pockets, cutter blades, cutting structures, junk slots, and/or fluid flow paths that may be formed on or attached to exterior portions of an associated bit body. For embodiments such as shown in FIGS. **1**, **2** and **3**, a plurality of cutter blades **52** may form on the exterior of composite matrix bit body **50**. Cutter blades **52** may be spaced from each other on the exterior of composite matrix bit body **50** to form fluid flow paths or junk slots therebetween.

[0028] A plurality of nozzle openings **54** may be formed in composite bit body **50**. Respective nozzles **56** may be disposed in each nozzle opening **54**. For some applications nozzles **56** may be described as "interchangeable" nozzles. Various types of drilling fluid may be pumped from surface drilling equipment (not expressly shown) through a drill string (not expressly shown) attached with threaded connection **34** and fluid flow passageways **32** to exit from one or more nozzles **56**. The cuttings, downhole debris, formation fluids and/or drilling fluid may return to the well surface through an annulus (not expressly shown) formed between exterior portions of the drill string and interior of an associated well bore (not expressly shown)

[0029] A plurality of pockets or recesses **58** may be formed in blades **52** at selected locations. See FIG. **3**. Respective cutting elements or inserts **60** may be securely mounted in each pocket **58** to engage and remove adjacent portions of a downhole formation. Cutting elements **60** may scrape and gouge formation materials from the bottom and sides of a wellbore during rotation of matrix drill bit **20** by an attached drill string. For some applications various types of polycrystalline diamond compact (PDC) cutters may he satisfactorily used as inserts **60**. A matrix drill bit having such PDC cutters

may sometimes be referred to as a "PDC bit". It will be readily 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 composite 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. **1-4**.

[0030] A wide variety of molds may be satisfactorily used to form a composite matrix bit body and associated matrix drill bit in accordance with teachings of the present disclosure. Mold assembly **100** as shown in FIGS. **2** and **4** represents only one example of a mold assembly satisfactory for use in forming a composite 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.

[0031] Mold assembly **100** as shown in FIGS. **2** and **4** may include several components such as mold **102**, gauge ring or connector ring **110** and funnel **120**. Mold **102**, gauge ring **110** and funnel **120** may be formed from graphite or other suitable materials. Various techniques may be used including, but not limited to, machining a graphite blank to produce mold **102** with cavity **104** having a negative profile or a reverse profile of desired exterior features for a resulting fixed cutter drill bit. For example mold cavity **104** may have a negative profile which corresponds with the exterior profile or configuration of blades **52** and junk slots or fluid flow passageways formed therebetween as shown in FIG. **1**.

[0032] As shown in FIG. **4**, a plurality of mold inserts **106** may be placed within cavity **104** to form respective pockets **58** in blades **52**. The location of mold inserts **106** in cavity **104** corresponds with desired locations for installing cutting elements **60** in associated blades **52**. Mold inserts **106** may he formed from various types of material such as, but not limited to, consolidated sand and graphite. Various techniques such as brazing, may be satisfactorily used to install cutting elements **60** in respective pockets **58**.

[0033] Various types of temporary displacement materials may be satisfactorily installed, within mold cavity **104**, depending upon the desired configuration of a resulting matrix drill bit. Additional mold inserts (not expressly shown) 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. Such mold inserts may have configurations corresponding with desired exterior features of composite bit body **50** such as fluid flow passageways formed between adjacent blades **52**. As discussed later in more detail, a first matrix material having increased toughness or resistance to fracture may be loaded into mold cavity **104** to form portions of an associated composite matrix bit body that engage and remove downhole formation materials during drilling of a wellbore.

[0034] Composite matrix, bit body **50** may include a relatively large fluid cavity or chamber **32** with multiple fluid flow passageways **42** and **44** extending therefrom. See FIG. **3**. As shown in FIG. **2**, displacement materials such as consolidated sand may be installed within mold assembly **100** at desired locations to form portions of cavity **32** and fluid flow passages **42** and **44** extending therefrom. Such displacement materials may have various configurations. The orientation and configuration of consolidated sand legs **142** and **144** may be selected to correspond with desired locations and configurations of associated fluid flow passageways **42** and **44** communicating from cavity **32** to respective nozzle outlets **54**. Fluid flow passageways **42** and **44** may receive threaded receptacles (not expressly shown) for holding respective nozzles **56** therein.

[0035] A relatively large, generally cylindrically shaped consolidated sand core **150** may be placed on the legs **142** and **144**. Core **150** and legs **142** and **144** may be sometimes described as having the shape of a "crow's foot." Core **150** may also be referred to as a "stalk." The number of legs extending from core **150** will depend upon the desired number of nozzle openings in a resulting composite hit body. Legs **142** and **144** and core **150** may also be formed from graphite or other suitable material.

[0036] After desired displacement materials, including core **150** and legs **142** and **144**, have been installed within mold assembly **101**), first matrix material **131** having desired fracture resistance characteristics (toughness) and erosion, abrasion and wear resistance, may be placed within mold assembly **100**. First matrix material **131** will preferably form a first zone or a first layer, which will correspond approximately with exterior portions of composite matrix bit body **50** that will contact and remove formation materials during drilling of a wellbore. The amount of first matrix material **131** added to mold assembly **120** will preferably be limited such that matrix material **131** does not contact end **152** of core **150**. The present disclosure allows the use of matrix materials having desired characteristics of toughness and wear resistance for forming a fix cutter drill bit or drag bit.

[0037] A generally hollow, cylindrical metal blank **36** may then be placed within mold assembly **100**. Metal blank **36** may comprise inside diameter **37** which is larger than the outside diameter of sand core **150**. Various fixtures (not expressly shown) may be used to position metal blank **36** within mold assembly **100** at a desired location spaced from first matrix material **131**.

[0038] Second matrix material **132** may then be loaded into mold assembly **100** to fill a void space or annulus formed between outside diameter **154** of sand core **150** and inside diameter **37** of metal blank **36**. Second matrix material **132** preferably covers first matrix material **131** including portions of first matrix material **131** located adjacent to and spaced from end **152** of core **150**.

[0039] For some applications second matrix material **132** is preferably loaded in a manner that eliminates or minimizes exposure of second matrix material **132** to exterior portions of composite matrix bit body **50**. First matrix material **131** may be primarily used to form exterior portions of composite matrix bit body **50** associated with cutting, gouging and scraping downhole formation materials during rotation of matrix drill bit **20** to form a wellbore. Second matrix material **132** may be primarily used to form interior portions and exterior portions of composite matrix bit body **50** which are not normally associated cutting, gouging and scraping downhole formation materials. See FIGS. **2** and **3**.

[0040] For some applications third matrix material **133** such as tungsten powder may then be placed within mold. assembly **100** between outside diameter **40** of metal blank **36** and inside diameter **122** of funnel **120**. Third matrix material **133** 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 metal shank **36**. Third matrix **133** may sometimes be

described as an "infiltrated machinable powder" Third matrix material **133** may be loaded to cover all, or substantially all, of second matrix material **132** located proximate outer portions of composite matrix bit body **50**. See FIGS. **2** and **3**.

[0041] During the loading of matrix material **131**, **132** and **133**, care should be taken to prevent undesired mixing between first matrix material **131** and second matrix material **132**, and undesired mixing between second matrix material **132** and third matrix material **133**. Slight mixing at the interlaces to avoid sharp boundaries between different matrix materials may provide smooth transitions for bonding between adjacent layers. Prior experience and testing has demonstrated various problems associated with infiltrating cemented carbides and spherical carbides with hot, liquid binder material when the cemented carbides and spherical carbides are disposed in relatively complex mold assemblies associated with matrix, bit bodies for fixed cutter drill bits. Similar problems have been noted when attempting to form matrix bodies with cemented carbides and/or spherical carbides for other types of complex downhole tools associated with drilling and producing oil and gas wells.

[0042] Manufacturing problems and resulting quality problems associated with using cemented carbides and/or spherical carbides as matrix material are generally associated with lack of infiltration, porosity, shrinkage, cracking and segregation of binder material constituents within interior portions of a resulting matrix bit body. Relatively complicated, intricate designs and relatively large sizes of many fixed cutter drill bits present difficult challenges to manufacturability of bit bodies having cemented carbides and/or spherical carbides as the matrix materials. These same quality problems may occur during manufacture of other downhole tools firmed at least in part by a matrix of cemented carbides and spherical carbides such as reamers, underreamers, and combined reamers/drill bits.

[0043] Previous testing and experimentation associated with premixing cemented carbides and/or spherical carbides with macrocrystalline tungsten carbide and/or cast carbide powders often failed to produce a sound, high quality matrix bit body. increasing soak time of binder material within such mixtures of cemented carbides and/or spherical carbides with macrocrystalline tungsten carbide and/or cast carbide powders did not substantially eliminate quality problems related to shrinkage, alloy segregation, lack of infiltration, porosity and other problems associated with unsatisfactory infiltration of cemented carbides and/or spherical carbides. Also, increasing the temperature of hot, liquid hinder material used for infiltration of such mixtures did not substantially reduce associated quality problems. Hid alloy segregation in the last solidifying portion of liquid binder material within various mixtures of cemented carbides and/or spherical carbides with macrocrystalline tungsten carbide and/or cast carbides was identified as one cause for lack of bonding within such mixtures, undesired shrinkage, porosity and other quality problems.

[0044] The use of first matrix material **131** to form a first layer or zone in combination with using second matrix material **132** to form a second layer or zone adjacent to first matrix material **131** may substantially reduce or eliminate alloy segregation in the last solidifying portion of hot, liquid binder material with first matrix material **131**. The addition of second matrix material **132** in the annulus formed between outside diameter **154** of core **150** and inside diameter **37** of metal blank **36** and covering first matrix material **131** such as shown in FIG. **2** may substantially reduce or eliminate problems related to lack of infiltration, porosity, shrinkage, cracking and/or segregation of binder constituents within first matrix material **131**. One reason for these improvements may be the ease with which hot, liquid binder material infiltrates macrocrystalline tungsten carbide and/or cast carbide powders.

[0045] As previously noted, hot, liquid binder material may leach or remove small quantities of alloys and/or other contaminates from bonding materials used to form cemented carbides. The leached alloys and/or other contaminates may have a higher melting point than typical binder materials associated with fabrication of matrix drill bits. Therefore, the leached alloys and/or other contaminates may solidify in small gaps or voids formed between adjacent cemented carbide pellets, spheres or other shapes and block further infiltration of hot, liquid binder material between such cemented carbide shapes.

[0046] The "contaminated" infiltrant or hot, liquid binder material may have solidus and liquidus temperatures different from "virgin" binder materials. Further "enrichment" of an infiltrant with contaminants may take place during solidification of the binder material as a result of rejection of solute contaminants into hot liquid ahead of a solidification front. Besides segregation of contaminants (solute) in later stages of solidification, any lack of directional solidification may give rise to potential problems including, but not limited to, shrinkage, porosity and/or hot tearing.

[0047] Macrocrystalline tungsten carbide and cast carbide powders may be substantially free of alloys or other contaminates associated with bonding materials used to form cemented carbides. The second matrix material may be selected to have less than five percent (5%) alloys or potential other contaminates. Therefore, infiltration of hot, liquid binder material through a second matrix material selected in accordance with teachings of the present disclosure will generally not leach significant amounts of alloys or other potential contaminates.

[0048] First 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 hit 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 sonic 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.

[0049] Second matrix material **132** may be monocrystalline tungsten carbide or cast carbide powders. Examples of such powders include P-90 and P-100 which are commercially available from Kennametal, Inc. located in Fallon, Nev. Third matrix material **133** may be tungsten powder such as M-70, which is also commercially available from H. C. Stuck, Osram Sylvania, and Kennametal. Typical alloy concentrations in second matrix material **132** may be between approximately one percent and two percent. Second matrix materials having an alloy concentration of approximately five percent or greater may result in unsatisfactory operating characteristics for an associated matrix bit body.

[0050] A typical infiltration process for casting composite matrix bit body **50** may begin by forming mold assembly **100**.

Gage ring **110** may he threaded onto the top of mold **102**. Funnel **120** may be threaded onto the top of gage ring **110** to extend mold assembly **100** to a desired height to hold previously described matrix materials and binder material. Displacement materials such as, but not limited to, mold inserts **106**, legs **142** and **144** and core **150** may then be loaded into mold assembly **100** if not previously placed in mold cavity **104**. Matrix materials **131**, **132**. **133** and metal blank **36** may be loaded into mold assembly **100** as previously described.

[0051] As mold assembly **100** is being filled with matrix materials, a series of vibration cycles may be induced in mold assembly **100** to assist packing of each layer or zone or matrix materials **131**, **132** and **133**. The vibrations help to ensure consistent density of each layer of matrix materials **131**, **132** and **133** within respective ranges required to achieve desired characteristics for composite matrix hit body **50**. Undesired mixing of matrix materials **131**, **132** and **133** should be avoided.

[0052] Binder material **160** may be placed on top of layers **132** and **133**, metal blank **36** and core **150**. In contrast to common practice, no flux layer is used on top of binder material **160**. A cover, or lid, **165** may be placed over mold assembly **100**. Mold assembly **100** and materials disposed therein may he preheated and then placed in a furnace (not expressly shown). When the furnace temperature reaches the melting point of binder material **160**, at least a portion (and typically substantially all) of the binder material **160** melts and liquefies such that the melted, liquid binder material **160** may infiltrate matrix materials **131**, **132** and **133**. As previously noted, second matrix material **132** allows melted, liquid binder material **160** to more uniformly infiltrate first matrix material **131** to avoid, in a subsequent process of solidification, the occurrence of undesired segregation in the last-solidifying portions of liquid binder material **160** with first matrix material **131**.

[0053] Upper portions of mold assembly **100** such as funnel **120** may have increased insulation (not expressly shown) as compared with mold **102**. As a result, hot, liquid binder material in lower portions of mold assembly **100** will generally start to solidify with first matrix material **131** before hot, liquid binder material solidifies with second matrix material **132**. The difference in solidification may allow hot, liquid binder material to "float" or transport alloys and other potential contaminates leached from first matrix material **131** into second matrix material **132**. Since the hot, liquid matrix material infiltrated through second matrix material **132** prior to infiltrating first matrix material **131**, alloys and other contaminates transported from first matrix material **131** may not affect quality of resulting matrix bit body **50** as much as if the alloys and other contaminates had remained within first matrix material **131**. Also, the second matrix material preferably contains less than four percent (4%) of such alloys or contaminates.

[0054] Proper infiltration and solidification of binder material **160** with first matrix material **131** is particularly important at locations adjacent to features such as nozzle openings **54** and pockets **58**. Improved quality control from enhanced infiltration of binder material **160** into portions of first matrix material **131** which forms respective blades **52** may allow designing thinner blades **52**. Blades **52** may also be oriented at more aggressive cutting angles with greater fluid flow areas formed between adjacent blades **52**.

[0055] For some fixed cutter drill bit designs forming a composite bit body with a first matrix material and a second matrix material in accordance with teachings of the present disclosure may result in as much as filly percent (50%) improvement in abrasion resistance, one hundred percent (100%) improvement in erosion resistance, fitly percent (50%) improvement in transverse rupture strength and sometimes more than one hundred percent (100%) improvement in impact resistance as compared with the same design of fixed cutter drill bit having a matrix bit body formed with only commercially available macrocrystalline tungsten carbide and/or cast carbide powders, or formulate thereof.

[0056] Mold assembly **100** may then be removed from the furnace and cooled at a controlled rate. Once cooled, mold assembly **100** may be broken away to expose composite matrix bit body **50** as shown in FIG. **3**. Subsequent processing according to well-known techniques may be used to produce matrix drill bit **20**.

[0057] As indicated above, in contrast to prior practice, no flux is used on top of binder **160**. It has been common practice in bit manufacturing to use a flux material over the copper binder. Fluxes are used to remove gases such as oxygen or hydrogen or prevent their absorption into the melt, to reduce metal loss such as zinc, and/or to remove impurities and nonmetallic inclusions from the melt. Borax ($Na_2B_4O_71OH_2O$) and boric acid (H_3BO_3) are considered neutral cover fluxes. Borax melts at 1365° F. and provides a fluid slag cover over the melt. These compounds are used in industry to reduce metal loss (zinc flaring) and to agglomerate and absorb nonmetallic impurities. However, our experience has shown that contamination of the flux with potassium borates and fluorides is possible. These compounds are commonly found in other fluxes and have been shown to inhibit proper wetting of WC particles by the binder leading to pockets of non-infiltrated loose powder in the bit head. in addition, numerous inclusions were identified in metallurgical test sections of manufactured bits. A test program was developed to determine the cause of the metallurgical defects in the bit manufacturing. The test program comprised melting an infiltrant binder in a small graphite crucible and lab furnace under varied furnace atmosphere, flux amount, time at temperature and physical exposure of the molten pool to the furnace atmosphere.

[0058] For each test, approximately 120 g of a copper binder, from Belmont Metals, Inc., Brooklyn, N.Y., was placed in the mold. Either 0 g, 2.4 g or 4.8 g of brazing flux, for example Harris 600 flux, manufactured by Harris Products, Mason, Ohio, constituting 0 wt %, 2 wt % or 4 wt % of the binder was added on top of the binder. The samples were placed into a lab furnace preheated to 2100° F., held at temperature for 10 or 30 min, removed and allowed to cool in ambient air. When a nitrogen atmosphere was used in the furnace, no atmosphere monitoring was performed. Nitrogen was fed into the furnace at 15 psi and positive pressure was used to inhibit air ingress. At 15 psi, three turns of the chamber atmosphere was estimated to occur in under 2 min, so minimum oxidation should have occurred after insertion of the samples. The introduction of nitrogen into the furnace also slowed the temperature recovery of the furnace by approximately one hour.

[0059] One known qualitative method used to estimate the gas content of a melt is to measure the surface shrinkage or "set" of the sample. All else being equal, samples with a greater amount of sink have a lower gas content, because less dissolved gas in the melt creates a smaller blowhole upon solidification when the gas is forced out of the metal. Each of

the samples were sectioned vertically to determine the relative size of the blowhole and amount of set, The samples without flux had the smallest blowholes and greatest amount of set as shown in FIG. **5**A. FIG. **5**A shows a cross sectioned example of a sample **500** manufactured without flux as contrasted to a sample **510**, see FIG. **5**B, manufactured with the flux described above. Sample **500** had 0 % by weight of binder **506**, and sample **510** had 2.4% by weight of binder **516**. The set **502** of sample **500** is significantly larger than the set **512** of sample **510**. In addition, the blow cavity **504** of sample **500** is significantly smaller than the blow cavity **514** of sample **510**. While presented in 2-dimensional format, it is understood that the blow cavities **504** and **514** are 3-dimensional cavities enclosed within the solidified samples, **500** and **510**, respectively.

[0060] Sections from each sample were mourned and polished. Twenty or more images for each sample were analyzed, un-etched at 100× magnification using image analysis software, for example Simagis brand image software, to determine the section inclusion content. Typical micrographs are shown in FIGS. **6**A-**6**C, where the flux content of the samples, was 0 wt %, 2% and 4%, respectively. As can he seen in comparing the micrographs, the inclusions, represented by the size and quantity of dark spots, increase progressively from the 0 wt % flux, to 2 wt % flux, to 4 wt % flux in the samples. These results were unexpected, since common practice taught to use flux to reduce impurities in the melt. No attempt was made to exclude solidification porosity from actual inclusions. The cooling conditions were similar for all samples so it is assumed they have comparable amounts of porosity. Again, the samples with more flux were "dirtier" than those with none.

[0061] The most prominent inclusion defect was only found in samples with flux. This defect was a boride intermetallic characterized visually by its opaque color and sharp corners. This intermetallic was found increasingly in samples as the flux addition increased and predominately influenced the inclusion levels identified. Thus, flux is, unexpectedly, directly causing intermetallic inclusion generation in the binder. A thin acicular needle inclusion was often associated with the boride intermetallic. The needle inclusion was too small for energy dispersive X-ray spectroscopy (EDS) analysis but is believed to also he a boride. Both of these inclusions were also found in the binder head of a production hit.

[0062] The second inclusion was manganese sulfide (MnS). This small inclusion has a dark gray color. Historically, higher concentration of this type of inclusion has been found near the hit surface. It is thought that the sulfur comes from the graphite molds.

[0063] Slag samples were taken from at least one flux covered binder test sample and analyzed using the EDS on the SEM. The results were compared to a similar slag sample removed randomly from a production bit before mold breakout. Both samples consist predominantly of manganese oxide and sodium oxide with trace amounts of silicon and aluminum oxides. Mn and Si are the most readily oxidized elements in binder while sodium is present in borax. (Boron is also likely present in the slag but is usually too light to detect with EDS) Even though the slag contains significant amounts of manganese, the amount lost to the slag was still insignificant to change the chemistry of the binder.

TGA Analysis

[0064] Thermogravametric analysis (TGA) was used to establish the onset of high temperature oxidation of both the binder and graphite. A small TGA sample was removed from a binder cube. In two separate tests, samples were heated continuously at 5° C./min or stepwise with 10 min. holds from 400° C. (842° F.) to 850° C. (1562° F.) in air with a purge rate of 100 mL/min. In both tests oxidation of the binder started above 900° F. and progressed exponentially as the temperature increase. The oxidation of graphite was also performed because the formation of CO may produce a reducing atmosphere inside the mold. A similar stepwise heating cycle with 10 min. holds from 400° C. (842° F.) to 850° C. (1562° F.) in air with a purge rate of 100 mL/min was performed on both the funnel graphite (grade CS) and mold graphite (grade CBY). Both grades start oxidizing around 1100° F. with the funnel graphite oxidizing slightly faster than the mold graphite at higher temperatures. Moreover, when carbon is oxidized at 1000° F., the reactant gas is around 90% CO_2 and only 10% CO. It is not until temperatures above 1500° F. are reached that the gas composition is over 90% CO. This means the graphite at temperatures below 1500° F. is not effective at preventing the oxidation of binder, but at 1700° F., when hinder is liquid and most active, the atmosphere is reducing (protective).

[0065] In view of the previous disclosure and unexpected laboratory results, one example of a new fluxless process for manufacturing a matrix drill bit may comprise placing at least a first layer of a first matrix selected from the group consisting of cemented carbides and spherical carbides material in a matrix bit body mold; placing a metal blank in the mold; placing at least a second layer of a second matrix material selected from the group consisting of microcrystalline tungsten carbide and cast carbide in the mold with the second matrix material operable to improve infiltration of a hot, liquid binder material throughout the first matrix material to minimize incomplete infiltration of the first matrix material by the hot, liquid binder material; placing a binder material in the mold with the binder material disposed proximate the second layer of matrix material and the metal blank; placing a graphite lid on the mold; heating the mold and the materials disposed therein in a furnace to a selected temperature to allow the binder material to melt, and to allow the hot, liquid binder material to infiltrate the second matrix material and the first matrix material with the second matrix material operable to improve infiltration of the first matrix material by the hot, liquid binder material; starting solidification of the hot, liquid binder material with the first matrix material before the hot, liquid binder material solidifies with the second matrix material; and cooling the mold and the materials disposed therein to form a coherent composite matrix hit body securely engaged with the metal blank.

[0066] Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alternations can he made herein without departing from the spirit and scope of the disclosure as defined by the following claims.

1. A fluxless process for manufacturing a matrix drill bit comprising:

placing at least a first layer of a first matrix material in a matrix bit body mold;

placing a metal blank in the mold;

placing at least a second layer of a second matrix material in the mold;

placing a binder material in the mold with the binder material disposed proximate the second layer of matrix material and the metal blank;

placing a graphite lid on the mold;

heating the mold and the materials disposed therein to a selected temperature to melt the binder material and to allow the melted binder material to infiltrate the second matrix material and the first matrix material, with the second matrix material operable to improve infiltration of the first matrix material by the melted binder material;

starting solidification of the hot, liquid binder material with the first matrix material before the hot, liquid binder material solidifies with the second matrix material; and

cooling the mold and the materials disposed therein to form a coherent composite matrix bit body securely engaged with the metal blank.

2. The process of claim **1** wherein the first matrix material is chosen from the group consisting, of: a cemented carbide material and a spherical carbide material.

3. The process of claim **1** wherein the second matrix material is chosen from the group consisting of a microcrystalline tungsten carbide material and a cast carbide material.

4. The process of claim **1** wherein the second matrix material is operable to improve infiltration of the hot, liquid hinder material throughout the first matrix material to minimize incomplete infiltration of the first matrix material by the hot, liquid binder material.

5. A process for reducing inclusions during manufacturing of a matrix drill bit comprising:

placing at least a first layer of a first matrix material in a matrix bit body mold;

placing a metal blank in the mold;

placing at least a second layer of a second matrix material in the mold;

placing a binder material in the mold with the binder material disposed proximate the second layer of matrix material and the metal blank:

placing a graphite lid on the mold;

heating the mold and the materials disposed therein to a selected temperature to cause the binder material to melt and to allow the hot, liquid binder material to infiltrate the second matrix material and the first matrix material, with the second matrix material operable to improve infiltration of the first matrix material by the hot, liquid binder material without using a flux material;

starting solidification of the hot, liquid binder material with the first matrix material before the hot, liquid binder material solidifies with the second matrix material; and

cooling the mold and the materials disposed therein to form a coherent composite matrix bit body securely engaged with the metal blank.

6. The process of claim **5** wherein the first matrix material is chosen from the group consisting of: a cemented carbide material and a spherical carbide material.

7. The process of claim **5** wherein the second matrix material is chosen from the group consisting of a microcrystalline tungsten carbide material and a cast carbide material.

8. The process of claim **5** wherein the second matrix material is operable to improve infiltration of the hot, liquid binder material throughout the first matrix material to minimize incomplete infiltration of the first matrix material by the hot, liquid binder material.

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