DRILL BITS AND METHODS OF PRODUCING DRILL BITS

Inventors: Arthur G. Wilder; Harold C. Bridwell, both of Salt Lake City, Utah

Assignee: Christensen Diamond Products Company, Salt Lake City, Utah

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Abstract

A diamond bit comprising a steel shank coated with abrasive particles, with a ring of tungsten-coated iron particles bonded together in a metal matrix and by metal to the end of the shank.

13 Claims, 5 Drawing Figures
3,757,879

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DRILL BITS AND METHODS OF PRODUCING DRILL BITS

This application is a continuation-in-part of Applications Ser. No. 219,973; 220,351; 220,352 filed Jan. 24, 1972.

This invention is an improvement on diamond drills in which diamonds are incorporated in the body of or positioned on the surface of an abraded structure in the form of a drill, for example, as may be used for earth boring.

In the conventional earth-boring drills, a plurality of different abrasive particles are employed. In addition to particles of high hardness values, for example, diamonds which act on the primary abrasive, there is positioned in the continuous phase of a metal matrix binder a secondary abrasive of lower hardness value.

The purpose of this secondary abrasive particle is to wear away preferentially to exposing new abrasive faces of the primary abrasive particle.

The abrader structures thus formed are deemed self-sharpening. That is, the matrix including the secondary abrasive wears away preferentially and uniformly exposing new primary abrasive cutting surfaces. This, however, tends to reduce the area of the interfacial surfaces between the bonding metal of the matrix and the primary and secondary abrasive particles. Where the bond is weak, the particles are torn out of the metal matrix, causing excessive wear.

In such a structure, it is conventional to form the abrader body of tungsten carbide to act as the secondary abrasive particle. The diamonds and tungsten carbide are bonded by means of a metal matrix which is formed by percolating molten metal to infiltrate the body of discrete tungsten carbide in a suitable mold to bond the tungsten carbide; if diamonds are also distributed throughout this metal matrix, the mixture of diamonds and tungsten carbide form the mass which is infiltrated by the molten metal. In another form, the diamonds are positioned in space configuration on the external grinding surface of the drill. These are termed surface set diamond drills.

There are a number of difficulties in forming such drills arising from the nature of the tungsten carbide as the secondary abrasive and the diamonds as the primary abrasive.

One of the problems arising when using tungsten carbide and diamonds in such structures is the restriction which it places on the machinable metal which may be used for the purpose of producing the machinable section of the bit.

The form of the drills includes a hollow steel shank coated at its exterior surfaces and over its end forming the crown end of the drill, with a metal bonded sheath of abrasive particles bonded to the steel shank by the metal.

It is desirable to cover the end of the metal bonded sheath at its end away from the crown end with a smooth bevel end. Such a structure would have the advantage that the bit when withdrawn from the bore hole would not hang up on a projection in the bore hole or the end of a casing section through which it is to be removed. However, the abrasive sheath is not conveniently machinable.

In order to solve this difficulty, we place a ring of machinable metal such as iron or nickel or alloys of these metals over the end of the abrasive section.

Conveniently, this may be done by providing a ring of such metal powder so that when the sheath is formed it will be welded to the body and may be machined to suitable form.

However, since the structure is formed under fusion conditions, there is a danger that the molten machinable metal will invade the body of the sheath and attack the tungsten carbide and diamonds. Diamonds and tungsten carbide are attacked by iron-based or nickel-based alloys. The W,C tungsten carbide is attacked or dissolved in the binder, and on freezing precipitates a new phase called Eta. This phase is an M,C type carbide, and in the case of nickel binders will have the composition Ni,W,C. Eta phase is more brittle than the original particle. The particle is said to be "haloed." The "haloed" portion of particle will have a hardness only of about 1,500 kilograms per square millimeter, compared, for example, to 1,950 to 2,100 kilograms per square millimeter (Knoop) for the core of the particle.

Tungsten carbide has been used in the past among other properties because of its high specific gravity, hardness, and high melting point.

The bonding metal chosen should be fluid at the temperature at which it is desired to employ the molten metal in forming the composite drill structure, for example, below 2,000°F. and desirably should have, when solid, ductility as measured in the terms of micro-hardness of below about 400 kg/mm². Desirably, also, it should have a compressive strength above about 90,000 p.s.i. and an impact strength above about 5 foot pounds.

For this purpose, we may use copper-based alloys such as brass and bronze alloys and copper-based alloys, for example, copper-based alloys containing various amounts of nickel, cobalt, tin, zinc, manganese, iron and silver, cast iron, iron-based alloys, nickel-based alloys, for example, nickel-copper-alumina-silicon alloy melting below 2,000°F.

We have found that we may use alumina, silicon carbide, boron nitride, and other abrasives as listed in Table 1 in place of tungsten carbide. The most practical both from point of view of economy and functional suitability are aluminum oxide, boron nitride, and silicon carbide. However, these materials may not be employed when a metal matrix is to be used as a bonding agent. The particles are not sufficiently wetted by the molten metal.

We have solved this problem by forming the drill bit by either the conventional procedures, using an abrader body for the bit formed of secondary abrasive such as tungsten carbide employing either the infiltrant method to produce a surface set diamond bit or an impregnated bit and forming at the upper end of the abrader body a ring of metal-bonded, metal-encapsulated iron or iron alloy. The secondary abrasive as well as the tungsten-coated iron is bonded with a molten metal forming a matrix. The iron ring after cooling is machined to a suitable shape.

In selecting the metal for the envelope when the encapsulated particle is to be used with metal matrix acting as a bonding agent, it is desirable that the metal in the envelope have a suitably higher melting point than the metal matrix.

We prefer to produce the aforesaid encapsulated iron particle by a process of chemical vapor deposition, by subjecting the abrasive particles to contact with a vola-
tile metal compound at an elevated temperature suffi
cient to maintain the metal compound in vapor form
and contact the vapor with a solid substrate under
metal deposition conditions.

While diamonds and the secondary abrasive may be
used as the primary abrasive and secondary abrasive in
encapsulated form, our invention permits their use in
unencapsulated form in the structure of our invention.

Cobalt-based, nickel-based, or iron-based alloys are
undesirable as metal-bonding agents since in their mol-
ten condition they attack tungsten carbide and the dia-
monds. The inclusion of these metals when used to pro-
duce the machinable portion of the drill is avoided in
our invention by the encapsulation of the particles of
these metals.

We prefer to use for encapsulation of the abrasive
particles and the aforesaid iron particles tungsten, tanta-
lum, niobium (columbium), and molybdenum, and,
among the primary abrasive particles, we prefer to em-
ploy diamonds, either the natural or synthetic forms;
and as secondary abrasive, we may use tungsten carb-
ide but we may employ encapsulated alumina, or en-
capsulated silicon carbide or encapsulated boron nitride
with tungsten carbide or the encapsulated alumi-
na most preferred because of the inherent properties
and relatively low cost of alumina, or boron nitride and
prefer to employ tungsten as the encapsulating ma-
terial, deposited under conditions to produce pure tung-
sten of the crystal form as described herein.

We prefer to employ as a bonding agent a metal hav-
ing a significantly lower melting point than the metal
envelope.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B.P. °C. at 760 m.m.*</td>
</tr>
<tr>
<td>Mo(mo)denum Penta(chloride) [MoCl₅]</td>
<td>268</td>
</tr>
<tr>
<td>Molybdenum Hexa(fluoride) [MoF₆]</td>
<td>35</td>
</tr>
<tr>
<td>Molybdenum Carbonyl [Mo(CO)₆]</td>
<td>156.4</td>
</tr>
<tr>
<td>Tungsten Pentabromide [WBr₅]</td>
<td>333</td>
</tr>
<tr>
<td>Tungsten Penta(bromide) [WBr₄]</td>
<td>17.5</td>
</tr>
<tr>
<td>Tungsten Pentachloride [WCl₅]</td>
<td>275.6</td>
</tr>
<tr>
<td>Tungsten Hexachloride [WC₆]</td>
<td>346.7</td>
</tr>
<tr>
<td>Tungsten Carbonyl [W(CO)₆]</td>
<td>175 at 766 m.m.</td>
</tr>
<tr>
<td>Tantalum Pentachloride [TaCl₅]</td>
<td>242</td>
</tr>
<tr>
<td>Tantalum Pentaffluoride [TaF₅]</td>
<td>229.5</td>
</tr>
<tr>
<td>Titanium Tetra(bromide) [TiBr₄]</td>
<td>230</td>
</tr>
<tr>
<td>Titanium Hexafluoride [TiF₆]</td>
<td>35.5</td>
</tr>
<tr>
<td>Columbium Tetrachloride [CbCl₄]</td>
<td>136.4</td>
</tr>
<tr>
<td>Columbium Pentabromide [CbBr₅]</td>
<td>361.6</td>
</tr>
<tr>
<td>Columbium Pentaffluoride [CbF₅]</td>
<td>236</td>
</tr>
<tr>
<td>Columbium Pentachloride [CCl₅]</td>
<td>236</td>
</tr>
</tbody>
</table>

* Unless otherwise indicated

When employing encapsulated or unencapsulated dia-
monds as the primary abrasive particle, we prefer to
limit the melting point of the metal matrix to a temper-
ature below about 2,800° F., i.e. 1,538° C., in order not
to expose the diamonds to excessive temperature which
may impair the mechanical strength of the diamonds.

We prefer to employ for the encapsulation of the
abrasive particles the reduction of a vapor of the metal
compound.

In view of the above consideration, the metals whose
compounds are listed in Table 1 may be employed;
however, we prefer to employ tungsten as an encap-
sulating metal because of its particular suitability in
the drill of our invention. It gives under the conditions
of fabrication according to our invention a coating of ex-
ceptionally high strength. It is readily wetted by the
molten metal matrices described above and forms a
strong metallurgical bond with the metal matrices em-
ployed in our invention.

The invention will be further described by reference
to the following figures:

FIG. 1 is a diagrammatic flow sheet of our preferred
process of encapsulation.

FIG. 2 is a schematic vertical section through a mold
for use in the infiltrant technique of forming a bit ac-
cording to our invention.

FIG. 3 is a partial section of one form of drill bit of
our invention.

FIG. 4 is a fragmentary view partly in section of a
modified mold.

FIG. 5 is a view partly in section of a modified drill
bit of our invention.

FIG. 1 illustrates a flow sheet of our preferred pro-
cess for producing the novel encapsulated abrasive of
our invention. The particles to be coated are placed in
the reactor 1, whose cap 2 has been removed. The re-
actor has a perforated bottom to support the particles
of selected mesh size. With cap 2 replaced and the
valves 3, 4, 5, and 13 closed, and with valve 7 open, the
vacuum pump is started to de-aerate the system. Valve
7 is closed and the system filled with hydrogen from hy-
drogen storage 11, valve 5 being open.

The reactor is heated by the furnace 9 to the reaction
temperature, for example, from about 1,000° to about
1,200° F. while purging slowly with hydrogen. The hy-
drogen flow rate is increased until a fluidized bed is es-
tablished. Hydrogen prior to introduction into the reac-
tor passes through a conventional palladium catalyst to
remove any impurities, such as oxygen in the hydrogen.
Vaporized metallic compound is discharged from the
vaporizing chamber 10, which may if necessary be
heated by furnace 14, together with an inert gas, for ex-
ample, argon from argon storage 6, into the reaction
chamber.

Preferably we desire to employ the volatile metal ha-
lices referred to above, although, in some cases, we
may use the carbonyls listed in Table 1. Where the ha-
lide is employed, the reaction forms hydrogen halide,
which is passed through the bubble traps and is ab-
sorbed in the absorber. Where the volatile compound
employed is a fluoride, the product formed is a hydro-
gen fluoride, and we may use sodium fluoride for that
absorption. We prefer to employ hydrogen in stoichoio-
metric excess.

The reaction deposits metal on the substrate and the
effluent material, being in the vapor state, is dis-
charged, leaving no contaminants on or in the metal.
The metal is formed in its pure state.

The rate of metal deposition depends on the tempera-
ture and flow rate of the reactants, being the greater
the higher the temperature and the greater the flow
rate of the hydrogen and volatile metals compound.

After the deposit is formed, the valves 4 and 5 are
closed and argon is continued to pass into the reactor
and the encapsulated abrasive is allowed to cool to
room temperature in the non-oxidizing condition of the
argon environment.

The conditions in the reactor, both because of the
mesh size and particle size distribution of the particles
and because of the velocity of the vapors and gases fluid-
dizes the particles. As will be recognized by those
skilled in the art, a dense phase is established in the
lower part of the reactor in which the particles are
more or less uniformly distributed in violent agitation
in the dense phase. This results in a substantially uni-
form deposit per unit of surface of the particles.
The reaction products and the carrier gases and excess hydrogen enter the upper space termed the disengaging space where they are separated from any entrained particles.

For purposes of illustration, not as limitations of our invention, the following examples are illustrative of the process of depositing a metal sheath upon a substrate.

The actual mesh size employed depends upon the service to which the abrader is to be placed. We may use iron particles of size (Tyler mesh) through 16 and on a 400 mesh (−16 + 400). Preferably we employ 30 to 100 mesh material, for example, −30 + 60 mesh. In depositing tungsten, we may and prefer to employ tungsten hexafluoride, which is contained and vaporized in 10. It is volatile at atmospheric temperatures and need not be heated. In the reactor employed after the system has been deaerated and backfilled, hydrogen flow is established at a low flow rate of about 100 ml/min; and as described above, the temperatures in the reactor having been adjusted to 1,150°F, as measured by the thermocouples, the hydrogen flow is increased to about 1,250–1,350 ml/min, and the flow of the tungsten fluoride vapor to about 150 ml/min and the argon gas is adjusted to about 285 ml/min, all as measured by the flow meters as indicated in FIG. 1, the hydrogen being in stoichiometric excess over the tungsten hexafluoride.

The thickness of the coat of the tungsten on the particle depends on the duration of the treatment and suitably for the 40 to 50 mesh diamonds described above, the coat will be 1 mil thick in about 1 hour. Suitable thickness deposit will run from about 0.1 to about 1.5 mils thick.

In the above example, the substrate surface is completely coated, indicating that the process of vacuum chemical vapor deposition has great throwing power. The outer surface of the coated particles is topographically congruent to the outer surface of the underlying substrate and reproduces it. The interlocked structure produces a coating of high tensile and bending strength.

The preferred embodiment of the surface set drill bit, as illustrated in FIGS. 2–4, may be formed in a graphite mold section 18, which is formed with sockets positioned in the interior surface of the mold. Diamond particles 19 are placed in the sockets positioned on the interior surface of the crown end of the mold.

With mold cap 24, section 18b and 18a removed and core 25 with vent holes 26 in position, a layer 20 of particles of tungsten carbide, such as described above, is placed in the mold 18 to cover the protruding diamonds and vibrated in position to compact the powder.

The threaded steel shank 15 is then placed over the mold above the powder 20, spaced from the surface of the mold 18, and held in position with a suitable fixture not shown.

Secondary abrasive particles, such as tungsten carbide, which may be but need not be encapsulated as described above, or, for example, encapsulated alumina particles 17 are introduced into the annulus at the exterior and in the annulus at the interior of the shank 15. The layer of the particles 17 in the exterior annulus reaches the level of the top of the mold section 18, but the powder in the interior annulus may, if desired, reach a higher level as shown.

The mold section 18a is then placed over the shank 15 and on the mold section 18. A ring of tungsten-coated iron particles 21 is placed in the exterior annulus over the particle section 17.

The mold section 18b is then set over the shank 15 and on the mold section 18a; and infiltrating metal powder 22, for example, of 200 mesh size such as described above, is introduced into the annulus on the exterior and the annulus at the interior of the shank 15 above the particles 21 and reaching into the space 23.

The ratio of the metal to the total void volume of the mold is desirably such that when the infiltrating metal melts it may fill all of the space between the secondary abrasive particles and cover the exposed diamonds.

As previously described, in carrying out this procedure, we wish to select a temperature of formation which will be below about 2,800°F, in order not to expose the diamonds to an excessive temperature. The binder metal will melt and percolate through the interstices including those in the encapsulated iron particles and those between the abrasive particles and fill all of the voids as described above and will also wet the metallic shank. If a metallic coating is placed upon the diamond as well as the secondary abrasive particles, the binder metal will wet the surfaces of the encapsulated particles, thus producing a tight bond to the matrix.

The particle sizes of the abrasive particles are chosen to give proper compaction and void area. A particle size through a 30 mesh and on a 60 mesh (−30 + 60) is suitable.

The tungsten-coated iron powder 21 is used to provide a machinable shoulder which acts as a barrier and cover to the exterior section of the abrasive section 17.

The tungsten envelope of the iron acts to protect the iron metal from escaping because its melting point will be below the temperature at which the mold is fired and could if it reached the unencapsulated diamonds or unencapsulated tungsten carbide attack them. It also provides for a machinable mass since the tungsten forms only a thin coat as described above.

The section is beveled as shown in FIGS. 3 and 5. This will assure that there is no exterior ledge which would otherwise be formed by the secondary abrasive section which is substantially unworkable to provide for a bevel surface. In the absence of this beveled section, there would be a danger that the drill bit could hang up on the bore wall or be caught on casing section in which the drill string is to operate.

When the assembly has cooled, it is removed from the mold and the section 21 is machined as shown in FIGS. 3 and 5, the interior box threads can receive the pin and box connector 26 to assemble the drill.

The drill is thus composed of a tubular shank 15 carrying a threaded section 28. Bonded to the interior tubular surface and exterior tubular surface of the shank 51 and over its crown end a coating of abrasive particles 17 bonded by a metal matrix in the form shown in FIG. 3, the crown of said bit carries spaced diamonds embedded in said crown and protruding externally therefrom.

The encapsulation of the iron with the tungsten will prevent the iron from melting and percolating through the mass to attack the diamond and the tungsten carbide if used.

It will be understood that the iron may be any form of the iron, such as powdered cast iron, steel or other ferrous alloy.

A particularly useful tungsten carbide when used in either layer 20 or 17 is one ranging from WC having...
6.12 wt percent of carbon to W,C having a carbon content about 3.16 wt percent. A useful material is so-called sintered tungsten carbide and consists of micro-sized WC crystals and cobalt metal bonded by liquid phase sintering at high temperature. The cobalt content varies from 3 wt percent to over 25 wt percent. This material has a hardness of about 1,250 to 1,350 kg/mm² (Knoop). Another form of eutectic alloy containing about 4 percent by weight of carbon having a hardness in the range of 1,900 to 2,000 kg/mm² (Knoop) may also be used.

The drill described above may also be produced by an impregnation technique by mixing a primary abrasive, for example, diamonds with a secondary abrasive described above, for example, tungsten carbide.

In this case, the mold section 18a does not contain pockets for insertion of diamonds but is smooth. In all other respects, the mold is the same as the mold shown in FIG. 2. With the shank 15 and core 25 in position in section 18, a mixture of the metal-coated secondary abrasive and the primary abrasive, for example, diamonds is introduced in the same manner as is the case of 17 in FIG. 2. This forms a layer 26 extending part way up the exterior annulus of 15 and to a higher level in the annulus in the interior side of 15.

The section 18a is then placed in position and the layer 21 introduced. The section 18b is then placed in position and the infiltrant metal 22 is introduced into the space 23 and the cap 24 placed in position. The same procedure is then followed as described in connection with FIG. 2.

The mesh size of the infiltrant metal is suitably through a 200 mesh; and in both forms, the metal may be of the kind previously described as suitable for infiltrant purposes.

The mesh size of the secondary abrasive particles employed in the form shown in FIGS. 2 and 3 as well as in FIGS. 4 and 5 may be the same, and the size diamond particles employed in the mixture with the secondary abrasive used in forming the layer 26 may be equal to that of the secondary abrasive particles. The quantity of the diamond particles may be that of the secondary abrasive. The diamond particles and the secondary abrasive are intimately mixed to produce a uniform distribution.

Instead of employing a mixture of diamonds and secondary abrasive to form the entire layer shown at 26, we may proceed as in the case of the form described in connection with 2 and 5 employ an initial crown layer formed of the mixture of diamonds and secondary abrasive particle described for forming the crown layer 20 in FIG. 2. We may then introduce on top of the crown layer the material 17 and the layer of tungsten-coated iron as described in connection with FIG. 2 and complete the operation as described for the formation of the drill in connection with FIGS. 2 and 3.

The drill shown in FIG. 3 and also 5 is composed of a threaded shank 15 having a core 30 to act as the conduit for mud or other drilling fluid. The shank carries the abrasive coating 17 or 26 welded to the shank by the bonding metal which wets the shank at the high temperatures of the process. The abrasive coating extends part way along the exterior and interior surface of the shank and over the lower end of the shank away from the threaded free end 28, to form the hollow crown end 29 of the drill. In the form shown in FIG. 2,