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(54) **BORON ALUMINUM MAGNESIUM COATING FOR EARTH-BORING BIT**

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(57) **ABSTRACT**

A rotatable cone earth boring bit has a bearing system with at least on the surfaces being AlMgB14 alloy material. The alloy material also contains an alloying agent, which may be titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); or tungsten boride (W2B4). The surface containing the AlMgB14 alloy material may be a journal surface or thrust face on the bearing pin. The surface containing the AlMgB14 alloy material may also be a seal surface, either on a metal face seal or a gland on the bearing pin engaged by an elastomeric ring. The AlMgB14 alloy material may a coating or it may be a free-standing structural member within the bearing system.

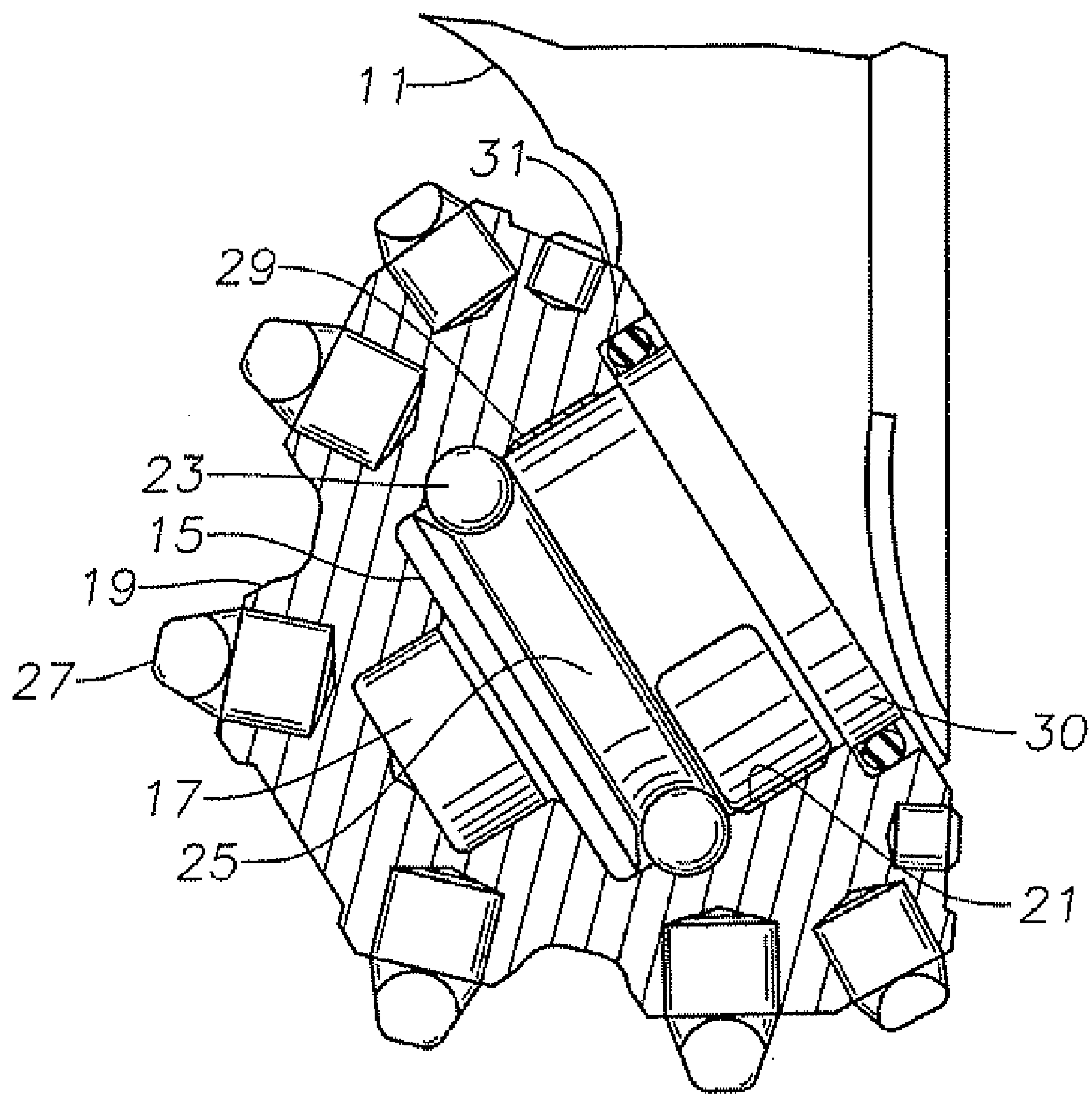


Fig. 1

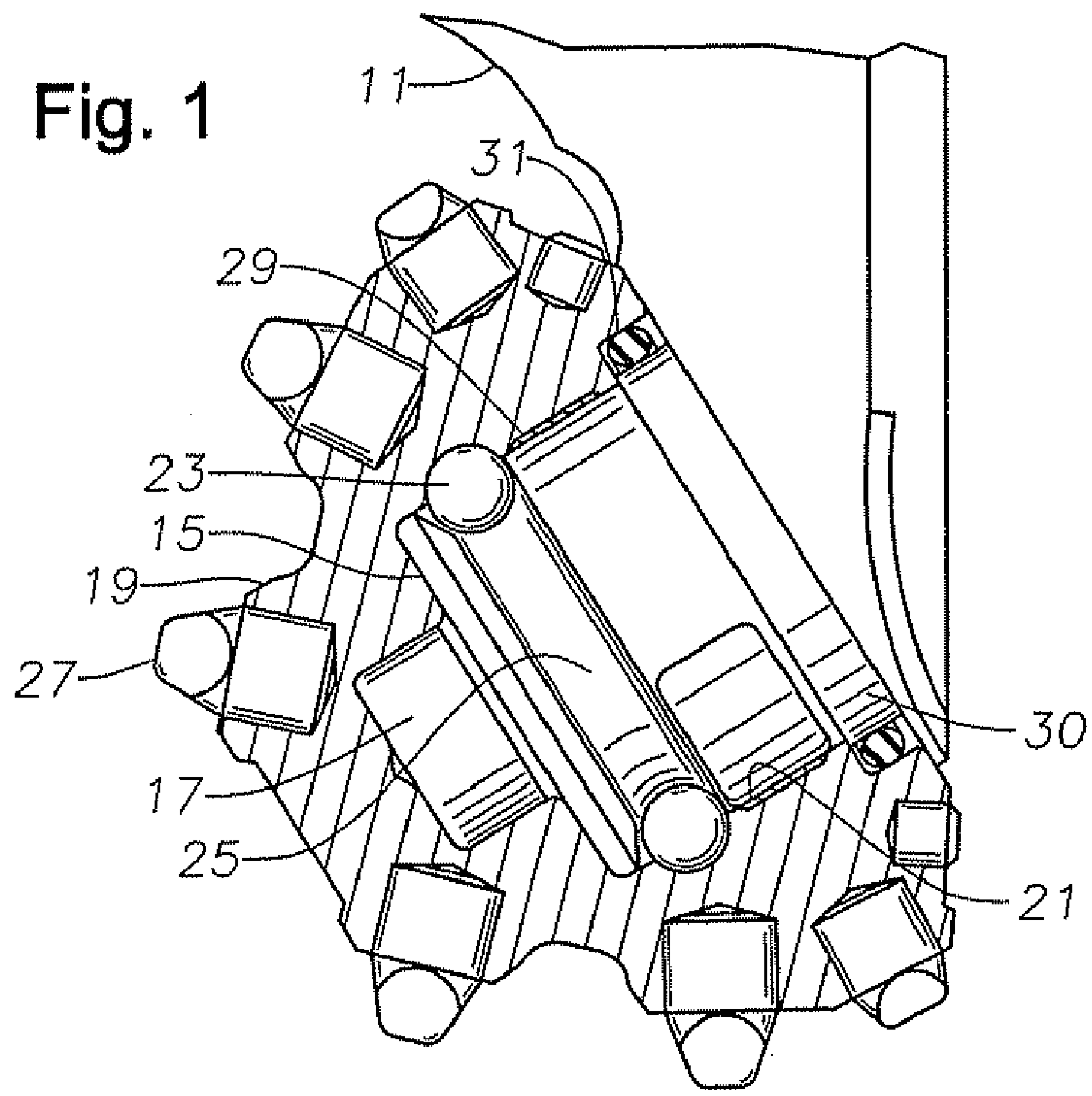


Fig. 2

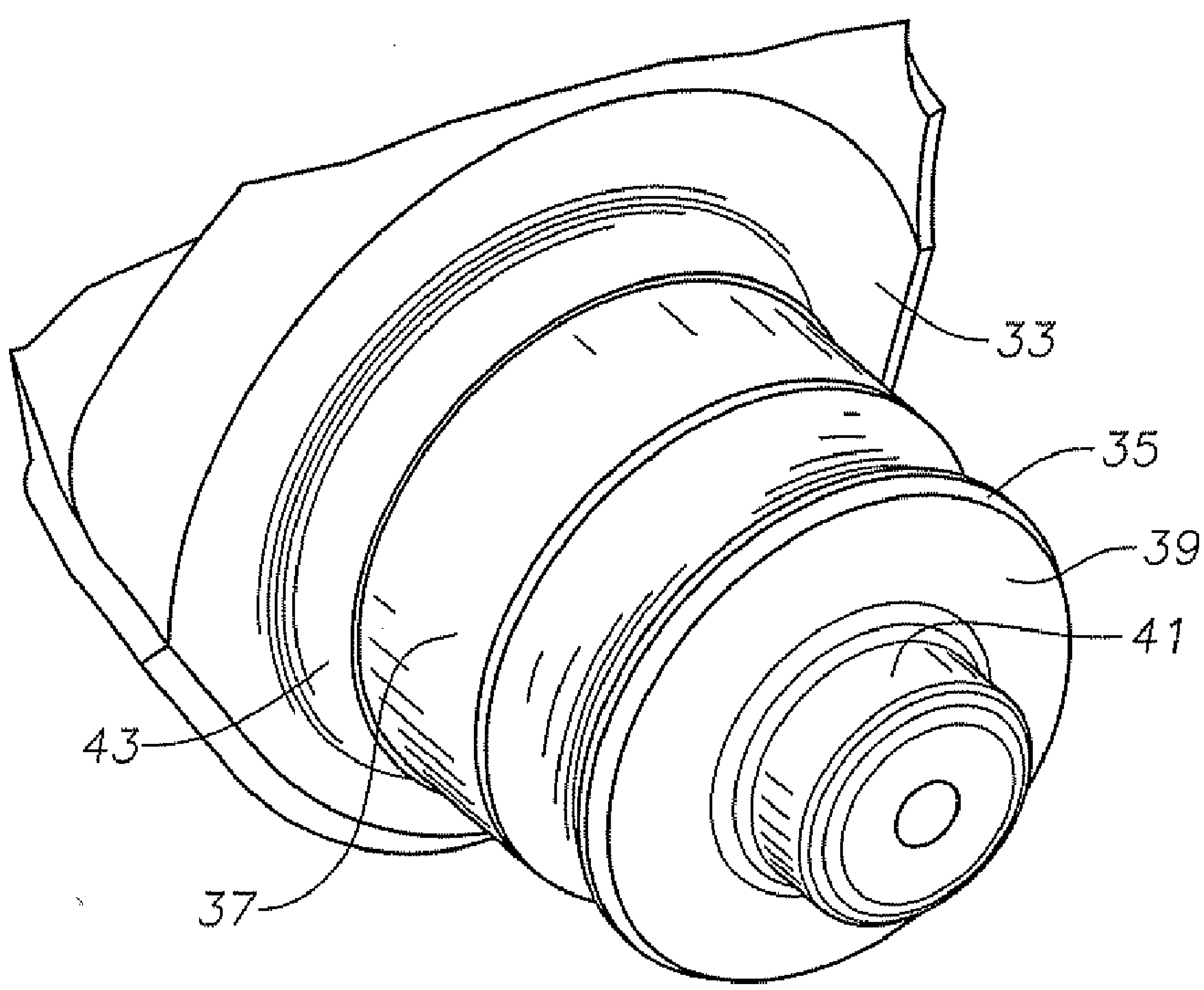
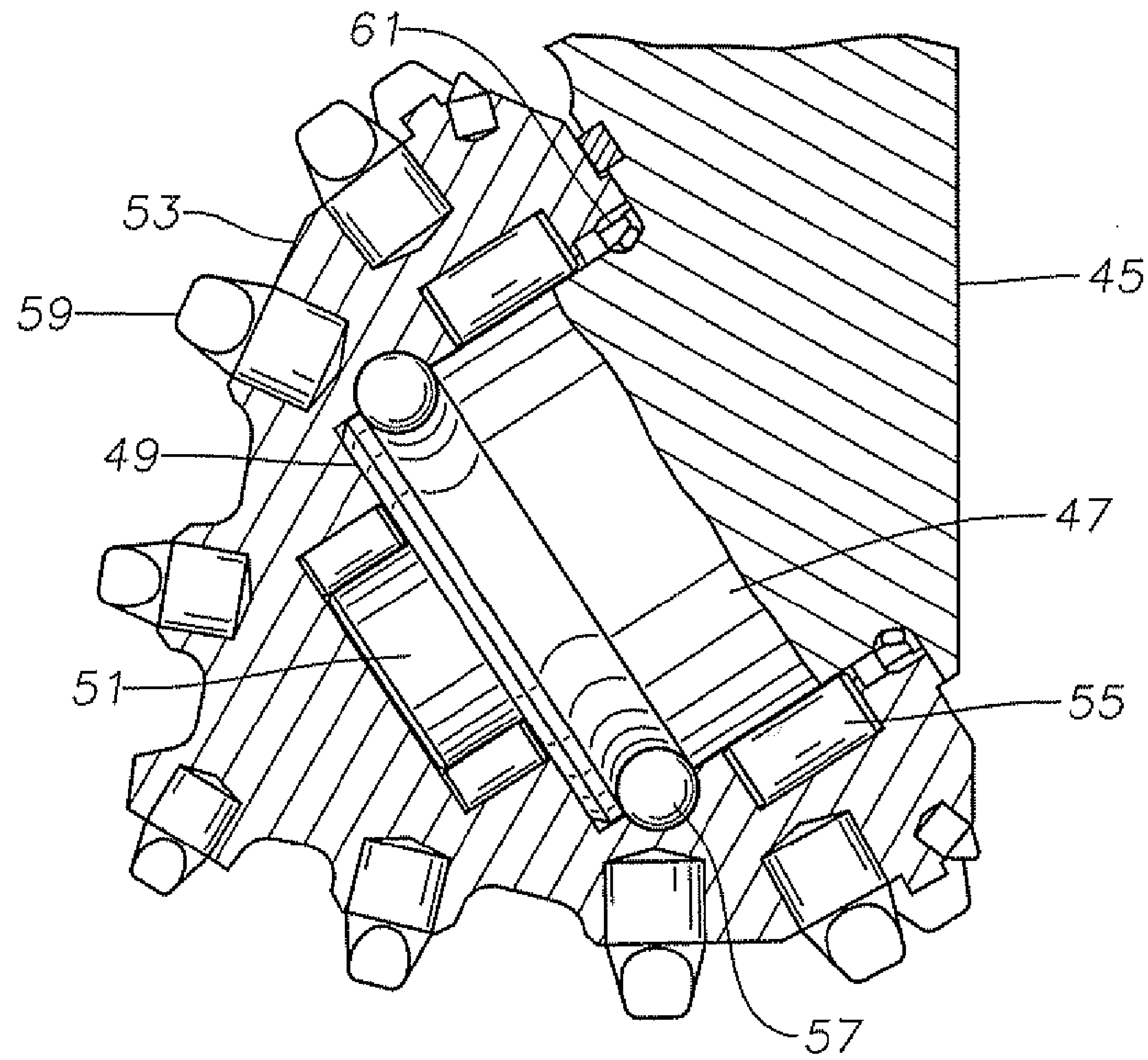


Fig. 3



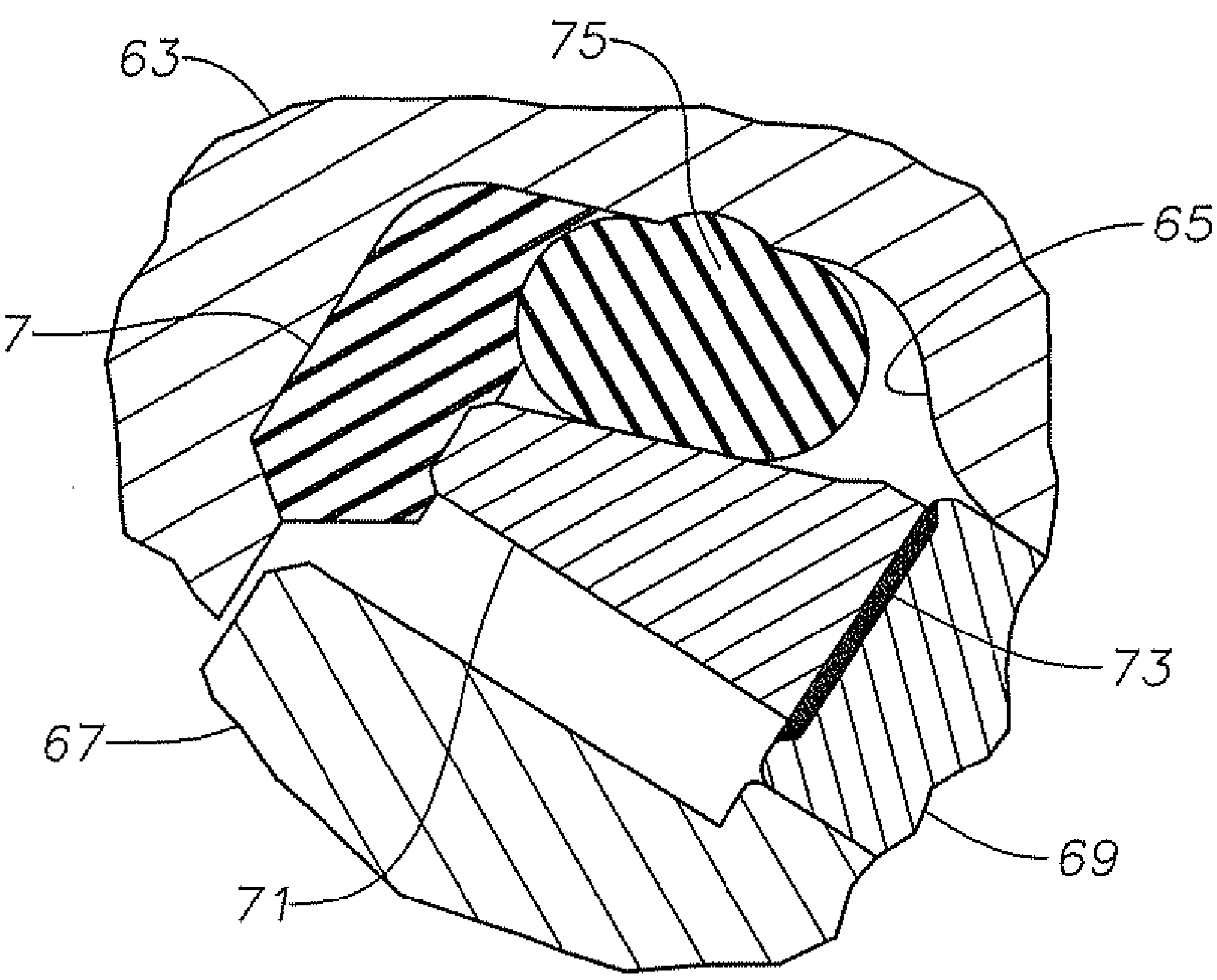


Fig. 4

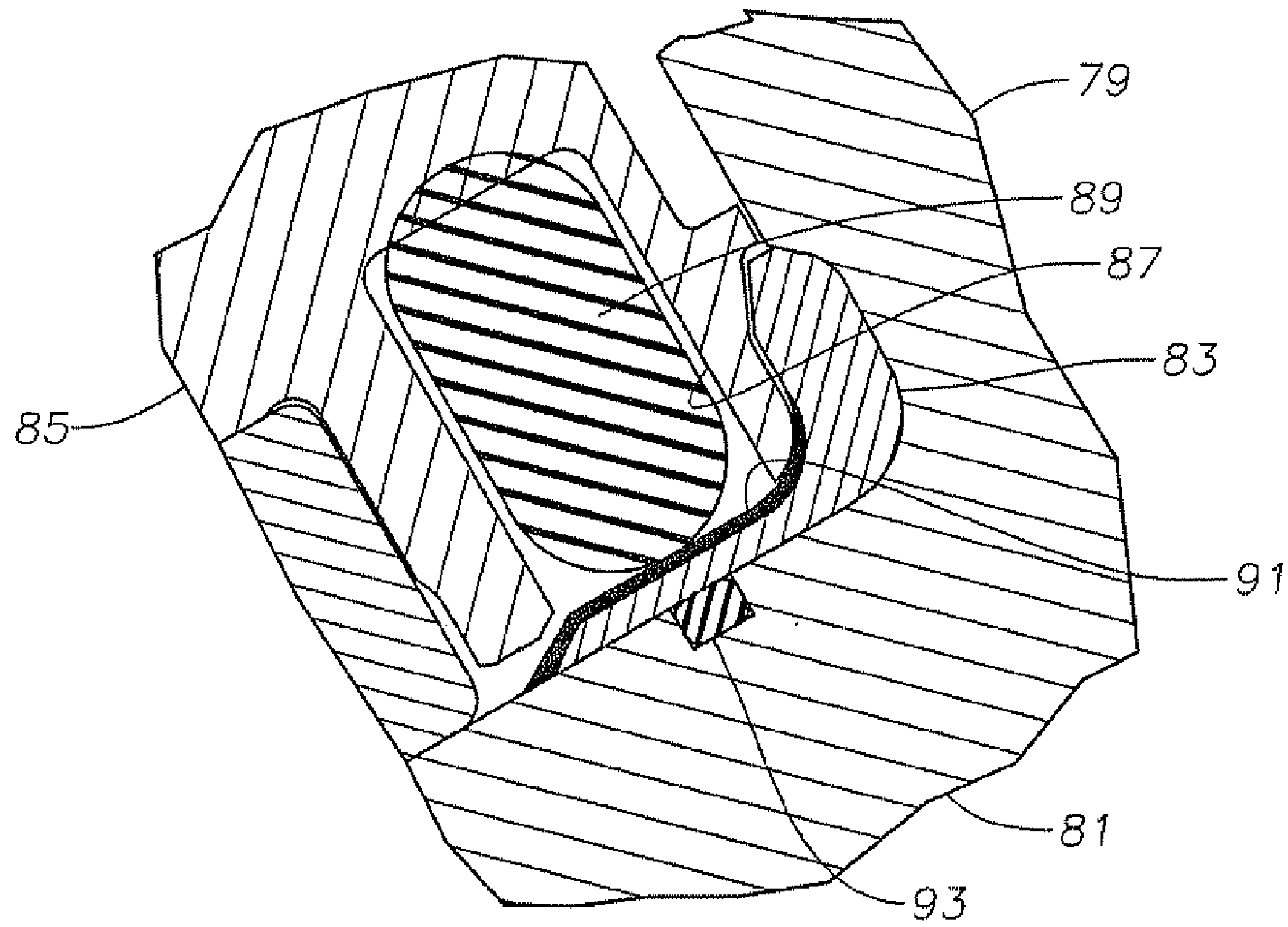


Fig. 5

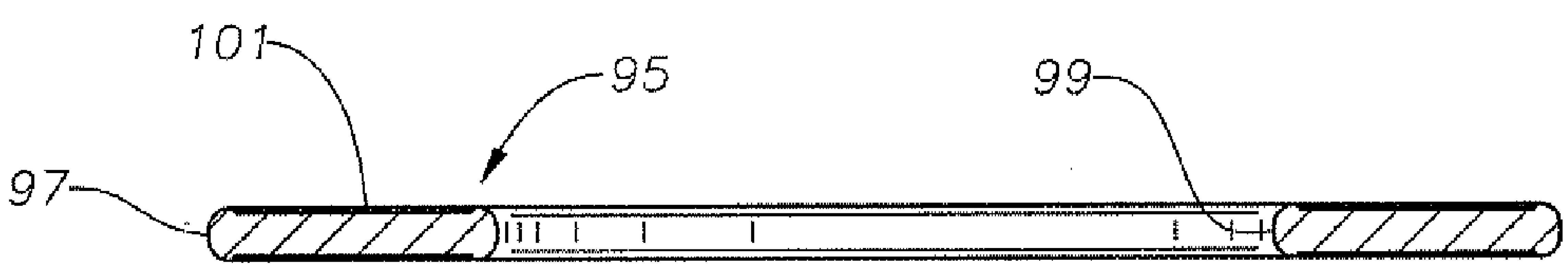


Fig. 6

BORON ALUMINUM MAGNESIUM COATING FOR EARTH-BORING BIT

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to provisional application 61/294,675 filed Jan. 13, 2010.

FIELD OF THE INVENTION

[0002] This application relates in general to hard coatings for improved abrasion resistance with reduced friction on downhole well tools such as rotary cone earth-boring bits, and in particular to coatings formed of boron, aluminum and magnesium.

BACKGROUND

[0003] One type of earth boring bit used in oil and gas well drilling has rotatable cones mounted to bearing pins of a bit body. The bearing system for the cones may be a journal bearing or a cylindrical roller bearing. The bearing system also includes thrust faces between the cone and bearing pin. A seal system seals lubricant within the bearing system. The seal system might be a metal-face-seal assembly, wherein an elastomeric member urges a metal-face seal into sliding engagement with a mating seal. Alternately, the seal system may comprise an elastomeric seal that is in sliding engagement with an annular gland journal on the bearing pin.

[0004] It is known that the journal bearing may be a bearing ring stationarily mounted around the bearing pin rather than the journal surface being the bearing pin itself. It is known that seal systems for earth boring bit bearings may employ a sleeve mounted around the bearing pin as the seal gland, rather than the seal gland being directly formed on the bearing pin.

[0005] Increasing the life of a bearing system is a continuing goal of earth boring bit manufacturers. It is known that various materials, such as diamond and diamond-like-carbon material, may be employed as the bearing and seal surfaces of the bearing system to enhance the life.

[0006] A recent type of lightweight, ultra-hard and wear resistant ceramics is in the area of complex ternary borides. These materials comprise aluminum magnesium boride alloyed with a few atomic percent group IV or group V elements as doping agents. The AlMgB14 intermetallic compound is based on four B12 icosahedral units positioned within an orthorhombic unit cell containing 64 atoms. The icosahedra are positioned at (0,0,0), (0,1/2,1/2), (1/2,0,0), and (1/2,1/2,1/2) while the Al atoms occupy a four-fold position at (1/4,3/4,1/4), and the Mg atoms occupy a four-fold position at (0.25,0.359,0). The hardness and wear resistance of this material are due to a complex interaction within each icosahedron (intrahedral bonding) combined with interaction between the icosahedra (intericosahedral bonding). The hexagonal icosahedra are arranged in distorted, close-packed layers.

[0007] The family of materials comprising AlMgB14 along with its alloys or doping agents is referred to herein as "BAM" materials. The alloy materials may include at least the following doping agents: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) as a powder or whiskered; boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4). The alloying may be by mechanical alloying consolidated by vacuum hot pressing or it may be by laser ablation and/or magnetron sputtering.

[0008] The alloying agents can increase the hardness by as much as 10-20%, depending upon the particular doping agent used. The dopants create distinct phases within the material that have nanophase grain sizes down to 100 nm (nanometer). The term "nanophase" is used to describe materials with phases less than 100 nm. In addition, some of the whiskered materials have fibers with diameters in the nanometer realm. The "whiskered" material referred to above is a form of a fiber composite. In brittle materials, it generally entails including a small volume fraction of fibers of one compound or phase with or within another non-fibrous larger constitutive phase. The larger volume fraction phase is sometimes considered the "matrix" phase. The general purpose of the inclusions is to divert and deflect the propagation of cracks through the body and also subsequently to perform negative work through friction as two fractured surfaces attempt to pull apart and withdraw embedded and still intact fibers from the matrix. In ceramic composites, the whiskers (or fibers) can be between microns and hundreds of microns long and microns in diameter all the way down to nanometer dimensions in both length and diameter. There are many factors that determine the optimization of both size and volume fraction of fibers used in a composite.

[0009] A suggested use for BAM alloy materials is abrasive cutting tools for industrial purpose. Applicants are not aware of BAM alloy materials being used or suggested for use in bearing systems.

SUMMARY

[0010] A downhole well tool has at least one rotatable member, a bearing system including a bearing member having bearing surfaces on which the rotatable member rotates and a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system. At least one of the surfaces comprises an AlMgB14 alloy material to enhance the life of the bearing system.

[0011] The alloy material may include a dopant or alloy agent consisting of: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); or tungsten boride (W2B4). The dopant creates a phase within the alloy material that has a grain size less than 100 nanometers. If whiskered silicon nitride is used, it may comprise fibers having diameters less than 100 nanometers.

[0012] The AlMgB14 alloy material may be a coating on at least one of the surfaces of the bearing system. Alternately, it may be a free-standing structure bonded to or forming one of the surfaces of the bearing system.

[0013] The AlMgB14 alloy material may be located on and form a cylindrical journal surface on the bearing member. It may be a flat circular thrust face on the bearing member. The AlMgB14 alloy material may be on cylindrical surfaces of roller bearings if the well tool employs roller bearings.

[0014] The AlMgB14 alloy material may be on at least one of the seal surfaces. For example it may be on a seal face of a rigid face seal assembly. If an elastomeric seal is employed rather than a rigid face seal assembly, the AlMgB14 alloy material may be on the seal gland that is slidingly engaged by the elastomeric seal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 is a partial sectional view of a cone and bit leg of an earth-boring bit having coatings applied in accordance with this invention.

[0016] FIG. **2** is a perspective view of a bearing pin of an earth-boring bit having a bearing sleeve with a surface treatment applied in accordance with this invention.

[0017] FIG. **3** is a partial sectional view of an earth-boring bit cone and bearing pin having roller bearings, the roller bearings and other surfaces having surface treatments in accordance with this invention.

[0018] FIG. **4** is an enlarged partial sectional view of a metal face seal employable with an earth-boring bit, the metal face seal having surface treatments applied in accordance with this invention.

[0019] FIG. **5** is a sectional view illustrating an elastomeric seal being employed with a floating insert ring, the insert ring being employable with any of the embodiments above and having surface treatments applied in accordance with this invention.

[0020] FIG. **6** is sectional view of a thrust washer that may be employed with any of the embodiments above, the thrust washer having surface treatments in accordance with this invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to FIG. **1**, an example of a downhole well tool is illustrated. A bit leg **11** of an earth-boring bit is shown, the bit typically having three bit legs **11**. A bearing member or pin **13** extends downward and inward from bit leg **11**. Bearing pin **13** has a cylindrical journal surface that terminates in a downward and inward facing thrust shoulder or face **15**. The lower portion of the journal surface is the portion of bearing pin **13** that is subject to the highest forces during drilling. A cylindrical nose **17** extends downward and inward from thrust face **15**.

[0022] A rotatable member, which in this example comprises a cone **19**, mounts rotatably on bearing pin **13**. Cone **19** has a cavity **21** that conforms to the configuration of bearing pin **13**. Cone **19** may be retained on bearing pin **13** by a plurality of locking elements or ball bearings **23**. Ball bearings **23** are located within mating bearing races **25** formed on bearing pin **13** and in cavity **21**. Cone **19** has a plurality of cutting elements **27** that protrude therefrom for disintegrating the earth formation. A seal **31** is in dynamic, sliding contact with a seal surface **30** on bearing pin **13** adjacent where bearing pin **13** joins bit leg **11**. Seal **31** is illustrated as an elastomeric seal, but it could be a metal face seal assembly. Cavity **21** is filled with a lubricant, and seal **31** seals the lubricant within cavity **21** as well as preventing encroachment of drilling fluid from the well bore being drilled. Bearing pin **13** and the shell or body of cone **19** are typically formed of steel.

[0023] At least one of the surfaces of the bearing system is an ultra-hard and wear resistant ceramic material in the area of complex ternary borides and specifically comprising an AlMgB14 material. These materials comprise aluminum magnesium boride alloyed with a few atomic percent group IV or group V elements as doping agents. The AlMgB14 intermetallic compound is based on four B12 icosahedral units positioned within an orthorhombic unit cell containing 64 atoms. The icosahedra are positioned at (0,0,0), (0,1/2,1/2), (1/2,0,0), and (1/2,1/2,1/2) while the Al atoms occupy a four-fold position at (1/4,3/4,1/4), and the Mg atoms occupy a four-fold position at (0.25,0.359,0). The hardness and wear resistance of this material are due to a complex interaction within each icosahedron (intrahedral bonding) combined with interaction between the icosahedra (intericosahedral bonding). The hexagonal icosahedra are arranged in distorted, close-packed layers.

[0024] The family of materials comprising AlMgB14 along with its alloys or doping agents is referred to herein as "BAM" materials. The alloy or doping agents may include at least one of the following: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) as a powder or whiskered; boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4). Some of the doping agents other than silicon nitride may be available in a whiskered form. The alloying may be by mechanical alloying consolidated by vacuum hot pressing or it may be by laser ablation and/or magnetron sputtering.

[0025] The alloying agents can increase the hardness by as much as 10-20%, depending upon the particular doping agent used. The dopants create distinct phases within the material that have nanophase grain sizes down to 100 nm (nanometer). The term "nanophase" is used to describe materials with phases less than 100 nm. In addition, some of the whiskered materials have fibers with diameters in the nanometer realm. The "whiskered" material referred to above is a form of a fiber composite. In brittle materials, it generally entails including a small volume fraction of fibers of one compound or phase with or within another non-fibrous larger constitutive phase. The larger volume fraction phase is sometimes considered the "matrix" phase. The general purpose of the inclusions is to divert and deflect the propagation of cracks through the body and also subsequently to perform negative work through friction as two fractured surfaces attempt to pull apart and withdraw embedded and still intact fibers from the matrix. In ceramic composites, the whiskers (or fibers) can be between microns and hundreds of microns long and microns in diameter all the way down to nanometer dimensions in both length and diameter. There are many factors that determine the optimization of both size and volume fraction of fibers used in a composite.

[0026] The BAM materials may be formed into a free standing structural member that is attached to a downhole well tool. Alternately, the BAM materials may be applied as a thin film coating.

[0027] Bearing pin **13** and/or cavity **21** may have a number of BAM surface treatments **29** to prolong the life of the bearing surfaces between bearing pin **13** and cone **19**. The term "BAM surface treatment" refers to either a solid, free standing member of BAM materials attached to various parts of bearing pin **13** and/or cone cavity **21**, or to a coating applied to the steel surfaces of bearing pin **13** and/or cone cavity **21**. BAM surface treatment **29** is illustrated on the cylindrical journal surface of bearing pin **13**. BAM surface treatment **29** could optionally be located on only the lower or pressure side of bearing pin **13**. A corresponding BAM treatment **29** could also be on the mating portion of cavity **21**. Or, that portion of cavity **21** could contain a soft material, such as silver.

[0028] BAM surface treatments **29** may also be located on thrust face **15** and the cylindrical portion of nose **17**. Normally, the flat end of nose **17** does not engage a surface in cone cavity **21**, rather all of the thrust is handled by thrust face **15**. BAM surface treatments **29** could also be applied as coatings to ball bearings **23** and race **25**. Each BAM surface treatment **29** could be in dynamic contact with a steel surface, another surface containing a BAM surface treatment **29**, a soft metal or other type of surface.

[0029] FIG. **2** illustrates another example of a BAM surface treatment. A bit leg **33** has a bearing pin **35** generally as described above. However in this instance, the journal bearing surface is not formed directly on the bearing pin **35**. Instead, a bearing ring **37** is press-fitted over or otherwise fixed on bearing pin **35**. Bearing ring **37** may be composed entirely of BAM material or it may be a steel member that has a BAM surface treatment on at least the lower side of its exterior cylindrical surface.

[0030] In addition, the drill bit in FIG. **2** may have a BAM surface treatment on seal engaging surface or seal gland **43**. Seal surface **43** is located between bearing ring **37** and bit leg **33** and is an annular surface that will be engaged by an elastomeric seal, which is not shown in FIG. **2**. Bearing pin **35** in FIG. **2** also has a thrust face **39** and a nose **41** as illustrated also in FIG. **1**. Thrust face **39** and the cylindrical surface of nose **41** may have BAM surface treatments, as described in connection with FIG. **1**.

[0031] Referring to FIG. **3**, a somewhat different bit leg **45** and bearing pin **47** are illustrated. In this example, bearing pin **47** has a thrust face **49** and a nose **51** as described above. A cone **53** slidingly engages and rotates relative to bearing pin **47**; rather than a cylindrical journal bearing surface, roller bearings **55** are employed. Roller bearings **55** comprise individual cylindrical members that are located in the same area where the journal surface is located in FIGS. **1** and **2**. Cone **53** has cutting elements **59** and may be retained by ball bearings **57** in the same manner as illustrated above. A metal face seal **61** seals lubricant within the cavity of cone **53**. BAM surface treatments could be applied to a number of places on the bearing pin **47** and in cone **53**. These areas could include thrust face **49**, roller bearings **55**, ball bearings **57** and the dynamic sealing surfaces engaged by seal **61**.

[0032] Referring to FIG. **4**, a different type of seal assembly is illustrated that could be used in place of elastomeric seal **31** shown in FIG. **1**. The metal or rigid face seal assembly illustrated in FIG. **4** locates in a seal gland **65** between bit leg **63** and cone **67**. Cone **67** may have a sleeve **69** within its cavity that rotates with cone **67**. A metal or rigid seal ring **71** and a metal or rigid cone sleeve **69** have mating end faces **73** that slidingly engage each other. One or both end rigid faces **73** has a BAM surface treatment, which may be a coating or a separate member attached to end face **73**. As is conventional with this type of metal face seal, an elastomeric energizer ring **75** exerts a force on metal seal ring **71** against face **73** of cone sleeve **69**. Energizer ring **75** is non-rotating and is deformed between seal gland **65** in bit leg **63** and metal seal ring **71**. A backup ring **77** of elastomeric material may be deformed in seal gland **65** between one side of energizer ring **75** and also an end of metal seal ring **71**.

[0033] FIG. **5** illustrates another embodiment of a seal assembly that could be used in place of elastomeric seal **31** of FIG. **1** and metal face seal **61** of FIG. **3**. In FIG. **5**, bit leg **79** has a bearing pin **81** extending downward and inward. A floating sleeve **83** slides over bearing pin **81** and is fixed against rotation relative to bearing pin **81**. However, sleeve **83** is free to move slightly relative to the axis of bearing pin **81** because it has an inner diameter slightly larger than the outer diameter of bearing pin **81**. Floating sleeve **83** is also able to cock slightly relative to the axis of bearing pin **81**. Cone **85** has a seal groove or recess formed in it. An elastomeric dynamic seal **89** is located in recess **87** and deformed against floating sleeve **83**. Dynamic seal **89** will normally rotate with cone **85** and slide against the exterior cylindrical surface of floating sleeve **83**. Preferably a BAM surface treatment **91** is located on the portion of floating sleeve **83** that is slidingly engaged by dynamic seal **89**. A static seal **93** is located in a groove on bearing pin **81** to engage the inner diameter of floating sleeve **83**.

[0034] FIG. **6** illustrates a thrust washer **95** that could be employed in FIG. **1** between the thrust face **15** and the mating surface in the cavity of cone **19**. It could also be employed in FIG. **2** between thrust face **39** and a mating surface of the cone that fits on bearing pin **35**. It could also be employed in FIG. **3** between thrust face **49** and the mating surface in cone **53**. Thrust washer **95** is a flat washer having an outer diameter **97** and an inner diameter **99**. The inner diameter **99** will slide over the nose of the bearing pin and could optionally be prevented from rotating relative to the bearing pin. Thrust washer **95** contains BAM surface treatments **101** on one or both sides.

[0035] As mentioned, the various BAM surface treatments described in connection with FIGS. **1-6** may be free standing members attached to the downhole well tool, or they may be coatings. If coatings, they can be applied in many different ways. They may be applied as ceramic powders, ceramic coatings, thin film coatings sputtered from targets, thick film laser formed or ablated powders, thick film plasma spray powders and other known and similar coating techniques in the art.

[0036] The BAM alloy material has very good abrasion resistance and a low coefficient of friction, making it particularly suited for use in bearing systems of rotating cone earth boring bits.

[0037] While the specification discloses only a few embodiments, it should be apparent to those skilled in the art that various changes and modifications may be made. For example, the BAM alloy material could be used in non-lubricated bearing systems, such as air drilling bits, as well as bits having lubricated bearing systems. In addition, the BAM alloy material could be used in bearing systems of earth boring bits other than conventional three-cone bits.

1. A downhole well tool having at least one rotatable member, a bearing system including a bearing member having bearing surfaces on which the rotatable member rotates and a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system, the improvement comprising:
  at least one of the surfaces comprising an AlMgB14 alloy material.

2. The well tool according to claim **1**, wherein the alloy material further comprises a dopant selected from a group consisting of: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4).

3. The well tool according to claim **2**, wherein the dopant creates a phase within the alloy material that has a grain size less than 100 nanometers.

4. The well tool according to claim **2**, wherein the whiskered silicon nitride comprise fibers having diameters less than 100 nanometers.

5. The well tool according to claim **1**, wherein the AlMgB14 alloy material comprises a coating on said at least one of the surfaces.

6. The well tool according to claim **1**, wherein the AlMgB14 alloy material comprises a free-standing structure bonded to said at least one of the surfaces.

7. The well tool according to claim **1**, wherein said at least one of the surfaces is at least one of the bearing surfaces and which comprises:

a cylindrical journal surface on the bearing member.

8. The well tool according to claim **1**, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

a fiat circular thrust face on the bearing member.

9. The well tool according to claim **1**, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

cylindrical surfaces of roller bearings.

10. The well tool according to claim **1**, wherein said at least one of the surfaces is at least one of the seal surfaces and which comprises a seal face of a rigid face seal assembly.

11. The well tool according to claim **1**, wherein said at least one of the surface is the mating seal surface and which comprises an annular seal gland on the bearing member that is slidingly engaged by an elastomeric seal ring.

12. An earth boring bit, comprising:

at least one rotatable cone with external cutting elements;

a bearing system comprising:

a bearing pin having bearing surfaces on which the cone rotates;

a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system;

at least one of the surfaces comprising an AlMgB14 alloy material; and

the AlMgB14 bearing material having an alloying agent selected from a group consisting of: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4).

13. The bit according to claim **12**, wherein said at least one of the surfaces is at least one of the bearing surfaces and which comprises:

an exterior surface of a bearing ring stationarily mounted on the bearing pin and defining a bearing journal.

14. The bit according to claim **12**, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

a flat circular disk stationarily mounted on a thrust face of the bearing pin.

15. The bit according to claim **12**, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

cylindrical surfaces of roller bearings.

16. The bit according to claim **12**, wherein said at least one of the surfaces is at least one of the seal surfaces and which comprises a rigid seal face of a rigid face seal assembly.

17. The bit according to claim **12**, wherein said at least one of the surface is the mating seal surface and which comprises a sleeve mounted around the bearing pin and slidingly engaged by an elastomeric seal ring.

18. The bit according to claim **12**, wherein the AlMgB14 alloy material comprises a coating on said at least one of the surfaces.

19. The bit according to claim **12**, wherein the AlMgB14 alloy material comprises a free-standing structure bonded to said at least one of the surfaces.

20. An earth boring bit, comprising:

at least one rotatable cone with external cutting elements, the cone having a cavity with a bearing surface;

a bearing pin having a bearing surfaces on which the bearing surface of the cone rotates;

at least one of the bearing surfaces comprising an AlMgB14 alloy coating; and

the AlMgB14 bearing coating having an alloying agent selected from a group consisting of: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4).

21. The bit according to claim **20**, wherein:

the bearing surface of the bearing pin comprises an exterior surface of a bearing ring stationarily mounted on the bearing pin and defining a bearing journal; and

the coating is located on the exterior surface of the bearing ring.

* * * * *