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(54) **Title**: ROLLER BEARING ASSEMBLY AND ELEMENTS THEREOF, AND METHOD OF MAKING A ROLLER ELEMENT

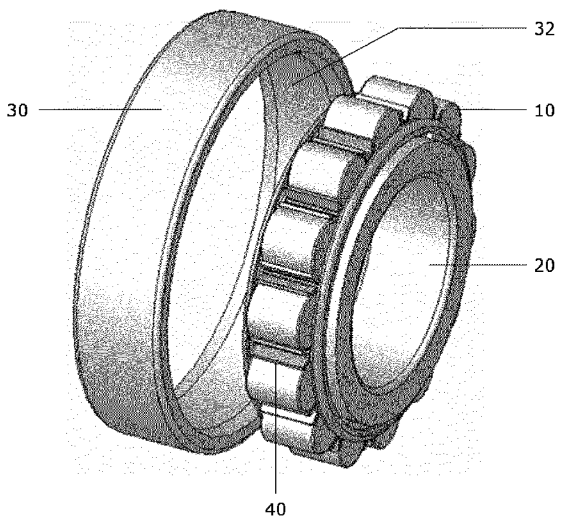

Fig. 1

(57) **Abstract**: A roller bearing assembly comprises a roller element comprising a roller bearing surface defined by a super-hard structure,and a race element comprising a race bearing surface, which may optionally also be defined by a super-hard surface. The race element and the roller element are configured such that the roller element can roll through at least one complete revolution about an axis of rolling rotation, throughout which rolling movement the roller bearing surface abuts the race bearing surface. The super-hard structure is configured such that the roller element is capable of supporting a load of at least 4,500 Newtons applied onto the roller bearing surface. A roller element is also described, and a method of making the roller element. The roller bearing assembly and roller element exhibit enhance wear resistance and find application, for example, in apparatus for boring into the earth, such as in roller cone bits, and in gear boxes, pumps compressors, milling apparatus and the like.

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ROLLER BEARING ASSEMBLY AND ELEMENTS THEREOF, AND METHOD OF MAKING A ROLLER ELEMENT

This disclosure relates generally to roller bearing assemblies, roller elements, race elements, liner structures for race elements and method for making roller elements, in which the roller element comprises a super-hard structure.

United States patent number 5,560,716 discloses a bearing assembly comprising opposed, uninterrupted diamond bearing surfaces, at least one of which is free of any Group VIII metal. Disclosed example bearing assemblies are reported as exhibiting a low friction coefficient of no greater than 0.1 and a high load-carrying capacity of at least 4,300 Newtons, equivalent to a contact pressure of at least 68 megapascals.

United States patent number 5,645,601 discloses a prosthetic joint for replacement of faulty natural joints, which significantly decreases load-bearing surface erosion and debris, and which has a low coefficient of friction between its load-bearing surfaces. The prosthetic joint may comprise a thin layer of diamond bonded to at least one of the bearing surfaces of the joint. The diamond compact is affixed to the bearing surfaces and processed in such a way as to give the diamond coating a high lustre and a low coefficient of friction. The diamond layer may be formed from a polycrystalline diamond compact sintered at ultra-high pressure, high temperature conditions and comprising diamond grains having diametrical size between one nanometres and ten microns.

United States patent number 6,290,726 discloses components for prosthetic joint implants having increased wear resistance and a decreased coefficient of friction. Super-hard materials such as diamond materials are used for the bearing surfaces of the joint, the super-hard materials including diamond being very resistant to wear and having a very low coefficient of friction.

United States patent number 8,016,889 discloses devices comprising diamond and sintered polycrystalline diamond (PCD) surfaces and articulating diamond-surfaced spinal implants. The PCD material provides a very strong, low friction, long-wearing surface in the implant, and form durable load bearing and articulation surfaces. The PCD material may be joined to a substrate or it may be free standing. Various other super-hard materials are disclosed for such devices, including mono-crystal diamond, natural diamond, diamond created by physical vapour deposition (PVD), diamond created by chemical vapour deposition (CVD), diamond like carbon (DLC) and cubic boron nitride (CBN).

The 8,016,889 patent explains that the CVD and PVD processes have some advantages over PCD, which is sintered in large, expensive presses at high pressure (such as 45 to 68 kilobars) and at high temperatures (such as 1,200 to 1,500 degrees Celsius). It is difficult to achieve and maintain desired component shape using a sintering process because of flow of high pressure mediums used and possible deformation of substrate materials. An additional difficulty with sintering shaped PCD constructions is that it is performed as a batch process that cannot be interrupted, and progress of sintering cannot be monitored. The pressing process must be run to completion and the part may only be examined afterward.

The 8,016,889 patent further explains that a range of challenges need to be addressed when sintering a construction comprising a PCD structure with a non-planar surface, associated with the fact that ultra-high pressure will need to be applied radially as well as axially in the sintering process. During this process, all displacements must be along a radian emanating from the centre of the part that will be produced in order to achieve the desired non-planar geometry. To achieve this in ultra high temperature, high pressure pressing, an iso-static pressure field must be created. During the manufacture of such non-planar parts, if there is any deviatoric stress component, it will result in distortion of the part and may render the manufactured part useless.

United States patent application publication number 20110079444 discloses bearing assemblies for use with earth boring drill bits having at least one roller cone, in which the bearing assembly may comprise a plurality of PDC bearing elements. For example, a cutting cone assembly may comprise a bearing means mounted within an interior region of a cone therein, and the bearing assembly may comprise a plurality of PCD bearing elements mounted on or within sleeve assemblies using brazing or other appropriate techniques.

United States patent application publication number 20120273282 discloses a bearing assembly including a roller bearing assembly, in which a diamond-like coating having a hardness of above 4,000 Vickers Hardness (HV) has been applied to each roller of each bearing race. The diamond-like coating may have a thickness greater than 10 microns, greater than about 50 microns greater than about 100 microns. Additionally, the diamond-like coating may exhibit a coefficient of sliding friction of about 0.07 to 0.08 against dry steel, or as low as about 0.035 against another diamond-like coating, at a relatively high surface pressure, such as at surface pressures greater than about 3 gigapascals.

JP2011153670 and WO2012/132968 similarly describe roller bearing surfaces coated with diamond-like coatings, and US 6,655,845 describes a variety of bearing and race components.

There is a need for roller-bearing assemblies and elements thereof having enhanced wear resistance.

Viewed from a first aspect, there is provided a roller bearing assembly comprising: (a) a roller element comprising a roller bearing surface defined by a super-hard structure; and (b) a race element comprising a race bearing surface; wherein the race element and the roller element are configured such that the roller element can roll through at least one complete revolution about an axis of rolling rotation, throughout which rolling movement the roller bearing surface abuts the race bearing surface, and the super-hard structure is configured such that the roller element is capable of supporting a load of at least 4,500 Newtons applied onto the roller bearing surface.

Various arrangements and combinations for bearing assemblies and roller elements are envisaged by this disclosure, non-exhaustive and non-limiting examples of which are described below.

In some embodiments the race bearing surface is also defined by a super-hard structure.

According to the first aspect there is provided a roller element which can “roll through at least one complete revolution about an axis of rolling rotation, throughout which rolling movement the roller bearing surface abuts the race bearing surface”. This means that the roller bearing surface that is defined by the super-hard structure is in contact with the race bearing surface during its complete revolution. Usually the super-hard structure extends all around the roller element. As the roller rolls in use it is the super-hard structure which contacts the race bearing surface.

In some example arrangements, the roller element and the race element may be configured for linear contact between them. In other example arrangements, the roller element and the race element may be configured for notionally point contact or circular contact between them. At least an area of the roller bearing surface may be right cylindrical in shape or substantially the entire roller bearing surface may have the shape of a right cylinder. The roller bearing surface may comprise a tapered or conical surface area, which may allow the bearing element to support simultaneously radial and axial force components. At least an area of the roller bearing surface may be conical in shape.

In some example arrangements, the roller bearing may be configured such that the roller bearing surface will appear circular when viewed in a cross section perpendicular to an axis of rolling rotation, the diameter of the cross sectional circle being at least about 2.5 millimetres and at most about 70 millimetres. In some examples, the roller bearing surface may have a radial dimensional variation of at most about 5 microns.

In some example arrangements, the roller element may have a length of at least about 4 millimetres and at most about 70 millimetres along an axis of rolling rotation.

In some example arrangements, the super-hard structure may comprise natural or synthetic diamond material and or cubic boron nitride (cBN) material. In various examples, the super-hard structure may comprise polycrystalline diamond (PCD) material and or polycrystalline cubic boron nitride (PCBN) material and or silicon carbide bonded diamond (SCD) material and or diamond film. The PCD and PCBN will have been sintered at ultra-high pressure of at least about 3 gigapascals, at least about 4 gigapascals at least about 5 gigapascals or at least about 6 gigapascals.

In some example arrangements, the super-hard structure may comprise a plurality of contiguous super-hard sub-structures, at least one of which is coterminous with the roller bearing surface. The term “sub-structure” is used here to mean a component structure in a larger overall structure. The prefix “sub” does not refer to any relative position or orientation of the component sub-structure to other components.

In some example arrangements, the super-hard structure may comprise a super-hard layer joined to a super-hard substrate. The super-hard structure may comprise a layer consisting of a diamond film attached to a super-hard substrate, a surface of the diamond film being coterminous with the roller bearing surface.

In some example arrangements, a layer comprising or consisting of diamond material or diamond-like carbon (DLC), which may be deposited by a PVD or CVD method, may be provided attached to an underlying super-hard structure, the layer having a surface coterminous with the bearing surface.

In some example arrangements, the super-hard structure may comprise a superhard layer joined to a super-hard substrate. The super-hard structure may be coterminous with the roller bearing surface. The super-hard structure may comprise, for example, a diamond layer sub-structure joined to an SCD sub-structure (comprising SCD material).In this case, the diamond layer sub-structure may comprise or consist of synthetic diamond material deposited onto the SCD sub-structure by means of a chemical vapour deposition (CVD) process. In some examples, the super-hard structure may comprise a layer of diamond film attached to a super-hard structure, a surface of the diamond film being coterminous with the roller bearing surface. In some embodiments the diamond film has a thickness of at least 5 microns and at most about 50 microns.

In some example arrangements, the super-hard structure comprises diamond material. In other embodiments it comprises SCD material, which in some examples may have a thickness between the opposite major boundaries of at least 2 millimetres and at most about 50 millimetres.

In some example arrangements, the super-hard structure may comprise PCD material. In these arrangements, in some embodiments, at least a surface region of the PCD material coterminous with the roller bearing surface may comprise a relatively small amount of solvent / catalyst material for diamond, or may be substantially devoid of solvent / catalyst material for diamond. For example, the surface region of the PCD material may comprise at most about 2 weight per cent of solvent / catalyst material for diamond. In some examples, the surface region of the super-hard structure may contain a plurality of voids. Example solvent / catalyst material for diamond may include iron, nickel, cobalt and manganese, and alloys or mixtures comprising one or more of these.

In some example arrangements, the super-hard structure may comprise super-hard material extending a depth of at least 0.5 millimetres from the roller bearing surface.

In some example arrangements, the roller element may comprise a super-hard structure attached to a substrate. The substrate may, for example, comprise cemented carbide material. The super-hard structure may be concentric with the substrate. The super-hard structure may be joined to the substrate at a side boundary of the substrate, the side boundary connecting a pair of opposite ends of the substrate, arranged such that the super-had structure is co-axial with the substrate. At least an area of the side boundary, or the entire side boundary may be conical or right cylindrical in shape.

In some example arrangements, the super-hard structure may connect opposite ends of the substrate. At least one of the ends may comprise super-hard material.

In some example arrangements, the roller element may comprise a conical layer of polycrystalline diamond (PCD) material bonded to a side boundary of a core substrate comprising cobalt-cemented tungsten carbide. The side boundary of the substrate may extend from a proximate generally circular end to a distal generally circular end. In some examples, the PCD layer may extend over substantially the entire side boundary of the core substrate, or the PCD may extend over only a part of the side boundary of the core substrate.

In some example arrangements, the super-hard structure may be in the form of a layer or tube having a thickness of at least 0.5 millimetres and at most about 5 millimetres. For example, the super-hard structure may comprise or consist of PCD material in the form of a layer or tube having thickness of at least about 0.5 millimetres or at least about 2 millimetres. The layer may have a thickness of at most about 2.5 millimetres or at most about 2 millimetres. In some example arrangements, the super-hard structure may be in the form of a layer or tube having substantially the same thickness at all points on a major part of or substantially the entire roller bearing surface (the thickness being measured radially from a point on the roller bearing surface with which the super-hard structure is coterminous)

In some example arrangements, the substrate may comprise an intermediate volume and a core volume comprising cemented carbide material, the intermediate volume being coterminous with the core volume and the interface boundary (with the super-hard structure); in which the intermediate volume comprises material having a coefficient of thermal expansion (CTE) at 25 degrees Celsius of greater than that of the super-hard structure and less than that of the cemented carbide material.

In some embodiments the super-hard structure connects opposite ends of the substrate.

In some example arrangements, the roller bearing may comprise a super-hard structure joined to a substrate. In some examples, the super-hard structure may be joined to the substrate by means of at least two intermediate layers between the super-hard layer and the substrate. In some examples, the super-hard layer may be joined to the cemented carbide core by means of two or three intermediate layers between the super-hard layer and the core. The intermediate layers may comprise grains of tungsten carbide and grains of a super-hard material dispersed in a matrix comprising cobalt. The content of the cobalt in intermediate layer may be less than that in layer, which is less than that in the core. Each intermediate layer may be at least about 0.2 millimetres thick and at most about 0.3 millimetres thick.

In some embodiments the superhard structure is in the form of a layer having a thickness of at least 0.5 millimetres and at most about 5 millimetres.

In some example arrangements, the roller bearing surface may have roughness of at most 0.6 micron.

In some embodiments the roller element has a pair of opposite ends connected by the roller bearing surface, in which at least one of the ends comprises super-hard material.

In some example arrangements, the race element may comprise a guide means for constraining the rolling movement of the roller element in use. In some examples, the race element may be in the form of a cup, ring or other generally annular body.

In some example arrangements, the race element may comprise ceramic material coterminous with the race bearing surface. Examples of suitable ceramic material include silicon carbide material, and/or super-hard material such as diamond material, and/or SCD material. In some examples, the race element may comprise a diamond film joined to SCD material, arranged such that a surface of the diamond film is coterminous with the race bearing surface.

In some example arrangements, the race element may comprise a liner structure attached to a support body, the liner structure having higher resistance to abrasive wear than the support body; the liner structure and the support body arranged such that a surface of the liner structure is coterminous with the race bearing surface. In some examples, the support body may comprise or consist of steel, and or cemented carbide material, and or SCD material, and or SCD material provided with a coating layer of CVD diamond material.

In some example arrangements, the liner structure may comprise or consist of super-hard material such as diamond material, and or SCD material coterminous with the race bearing surface. In some examples, the liner structure may comprise or consist of cubic boron nitride (CBN) material, and or PCD material, and or silicon carbide-bonded diamond (SCD) material, and or diamond film and or polycrystalline cubic boron nitride (PCBN) material. In some examples, the liner structure may comprise or consist of ceramic material such as silicon carbide, silicon nitride, aluminium oxide, aluminium nitride or silicon dioxide, which may be in sintered polycrystalline form. In some examples, the liner structure may comprise or consist of diamond-like carbon film.

In some example arrangements, the liner structure may comprise a diamond film coterminous with the race bearing surface. In some embodiments the diamond film has a thickness of at least 5 microns and at most about 50 microns.

In some example arrangements, the liner structure may comprise SCD material having a thickness between the opposite major boundaries of at least 2 millimetres and at most about 50 millimetres.

In some example arrangements, the liner structure may comprise a diamond film joined to SCD material, arranged such that a surface of the diamond film is coterminous with the race bearing surface.

In some example arrangements, the liner structure comprises a diamond-like carbon film coterminous with the race bearing surface.

In some example arrangements, the liner structure may be arcuate in shape, providing an arcuate race bearing surface. In some examples, the liner structure may be annular in shape. In some examples, the liner structure may comprise a plurality of liner sub-structures, configured to be capable of being attached to the support body contiguously with each other, which for example may be assembled as mosaics or circumferential segments.

In some example arrangements, the liner structure may be attached to the support body by means of braze material, epoxy adhesive material, mechanical interlock means or interference fit, such as may be achievable by means of press fitting of shrink fitting.

In some example arrangements, the liner structure may be capable of being coupled to the support body by means of a mechanical inter-lock mechanism such as a tongue-and-groove mechanism. For example, a slot may be provided into a proximate side of the support body, the slot and the liner structure being cooperatively configured such that at least a part of the liner structure can be accommodated within the slot. In some example arrangements, grooves may be formed into opposite sides of the liner structure, the grooves being cooperatively configured with corresponding tongues projecting from opposite sides of the slot, such that the liner structure can be slotted into the depression, the tongues inter-locking with the corresponding grooves operative to secure the liner structure within the slot. In some example arrangements, the support body may be in the form of a ring having a radially inner side into which a circumferential slot is formed, and into which a liner structure may me slotted when in an assembled condition.

In some example arrangements, a race element may comprise SCD material coterminous with the race bearing surface, the roller elements may comprise PCD material coterminous with the respective roller bearing surfaces.

In various example arrangements described above, one or more elements of the roller bearing assembly, for example one or more roller elements, and or one or more race elements and or a liner structure, may comprise or consist of SCD material. In some example arrangements, a layer of material, such as diamond or ceramic material, may be bonded to a boundary of the SCD material, for example by chemical vapour deposition (CVD) or physical vapour deposition (PVD). The SCD material will comprise a plurality of diamond grains dispersed in and chemically bonded to a matrix comprising or consisting of silicon carbide material,. In some examples, the matrix may comprise the alpha and or beta polymorph of silicon carbide. In some examples, the matrix may contain a minor amount of silicon other than in silicon carbide form. For example, the matrix may contain silicon in elemental, unreacted form, and or in the form a compound including oxygen. The content of silicon other than in silicon carbide form may be at most about 10 weight per cent or at most 5 weight per cent, or the SCD material may be substantially free of such silicon. The silicon carbide material may account for at least about 35 per cent and or at most about 75 per cent of the volume of the SCD material. The SCD material may comprise 35 to 75 volume per cent of silicon carbide material. The diamond grains may account for at least about 25 volume per cent and or at most 65 volume per cent of the volume of the SCD material. The SCD material may comprise 25 to 65 volume per cent diamond grains. In some examples, the SCD material may comprise diamond grains having mean equivalent circle diametrical size of at least about 5 microns and or at most about 250 microns (as measured by examining a surface of the SCD material and using an equivalent circle approach, suitably corrected to convert the size distribution in terms of two dimensions to one for grains in three dimensions).

In various example arrangements described above, one or more elements of the roller bearing assembly, for example one or more roller elements, and or one or more race elements and or a liner structure, may comprise a diamond layer or film. In various examples, the diamond layer may comprise micro-crystalline or nano-crystalline diamond grains, and may be deposited onto a body using a microwave generated plasma or a cathode hot filament deposition process. The thickness of the CVD layer may be in the range of about 5 microns to about 50 microns, or in the range of about 5 microns to about 30 microns, or in the range of about 10 microns to about 20 microns.

In some example arrangements, the roller bearing assembly may be configured to be capable of transmitting axial thrust load and supporting radial load components. For example, an inner race element may comprise a conical race bearing surface and an outer race element (which may be referred to as a cup), at least a part of which may be annular, may have a correspondingly inclined race bearing surface. The angle of inclination of a race bearing surface (which may be referred to as the “entry angle”) may be configured according to the desired ratio of the thrust (axial) and radial components of a load in use, higher entry angles tending to be relatively more suitable for higher levels of thrust loading. For example, the entry angle may be in the range of about 20 degrees to about 55 degrees relative to the axis of rotation of a race element. The inner and outer race elements will be configured such that the roller elements can be accommodated between their respective race bearing surfaces, inclined at an angle corresponding to the conical surface of the inner ring. The inner and or outer race elements may comprise high carbon content chrome steel. The roller elements may comprise conical bearing surfaces, each having an overall tapered shape.

In some example arrangements, the roller elements may be located in respective cages when the bearing assembly is in the assembled condition. The cages may comprise high carbon steel, brass, PTFE or polymer materials, depending on the intended application of the bearing assembly.

Roller bearing assemblies according to this disclosure may be used in various kinds of drill bits for boring into the earth, including roller cone bits, core bits, eccentric bits, bi-centre bits, reamers, mills, hybrid bits employing both fixed and rotatable cutting structures, and other drilling bits and tools comprising rotatable components. Various types of drilling tools for boring into the earth include rotary drill bits, such as roller cone bits, which may comprise a plurality of cutter bodies, each mounted onto a respective member (which may be referred to as a “leg”) extending from a bit body.

Viewed from a second aspect, there is provided a roller element for a roller bearing assembly according to the present disclosure, comprising a super-hard structure defining a roller bearing surface and configured operable to roll against a body through at least one complete revolution about an axis of rolling rotation, the roller bearing surface abutting the body throughout the revolution, the super-hard-structure being configured such that the roller element is capable of supporting a load of at least 4,500 Newtons applied onto the roller bearing surface.

The roller bearing assembly and roller bearing disclosed herein may be used for example in a gear box, pump, compressor or turbine for generating electricity, reamer, milling apparatus, or in a drill bit for boring into the earth for example in a roller cone bit, core bit, eccentric bit, bi-centre bit or hybrid bit.

Viewed from another aspect, there is provided a method for making a roller element according to this disclosure, the method including providing a precursor body comprising an elongate, generally annular super-hard layer joined to a circumferential side surface of a cemented carbide core substrate, and processing the precursor body to final dimensions and surface finish.

Solvent / catalyst material can be removed from the surface region by means of treating the PCD material with suitable acid liquor for a sufficiently long period of time, by a process known as acid leaching, for example. The acid liquor may include hydrochloric acid, for example. Prior to removal, the PCD material will likely contain filler material between the diamond grains, the filler material comprising or consisting of solvent / catalyst material for diamond that had become entrapped within the PCD microstructure during the sintering process.

In some examples, the precursor body may comprise a pair of opposite ends connected by the side surface and the super-hard structure may extend circumferentially all the way around the core. In some examples, the super-hard structure may comprise or consist of PCD material and the precursor body may be manufactured by sintering together an aggregated plurality of diamond grains onto the side surface of the core at an ultra-high pressure and high temperature.

Non-limiting example arrangements will be described with reference to the accompanying drawings, of which

Fig. 1 shows a schematic perspective view of an example cylindrical roller bearing assembly, shown in partly assembled condition;
Fig. 2A shows a schematic perspective view of an example taper cylindrical roller bearing assembly, shown in partly assembled condition, and Fig. 2B shows a schematic axial cross section view of the example bearing assembly;
Fig. 3 shows a schematic cross section view of parts of an example bearing assembly in an unassembled condition;
Fig. 4A to Fig. 4F show schematic cross section views of parts of various kinds of roller bearing configurations, in which a straight roller element is shown in Fig. 4A, a spherical roller bearing is shown in Fig. 4B, a tapered thrust bearing is shown in Fig. 4C, a tapered

roller is shown in Fig. 4D, a needle bearing is shown in Fig. 4E and a steep-angled tapered bearing is shown in Fig. 4F;

Fig. 5 shows a schematic perspective view of an example roller element;

Fig. 6 shows a schematic cross section view of an example race for a bearing assembly; and

Fig. 7 shows a schematic partly cut-away side view of an example roller cone drill bit

A roller element can be contrasted with a plain bearing element, which does not roll in use and may comprise a planar bearing surface. Roller bearings may be broadly distinguished as point- and linear contact bearings, the former being idealised ball bearings and examples of the latter including cylindrical, tapered and needle roller bearings. In practice, contact will be neither at a point nor a line (strictly speaking), since the curved roller bearing surface will tend to flatten slightly under load and therefore contact will be over a surface area. Nevertheless, linear contact bearings will have an elongate line of contact while point contact bearings will have a localised, generally circular area of contact. Linear contact roller elements are generally elongate, comprising a pair of opposite ends connected by a side surface on which the element is capable of rolling at least one complete revolution, at least part of the side surface capable of functioning as a bearing surface. Linear contact roller bearings generally have cylindrical symmetry, a notional longitudinal cylindrical axis extending through respective centres of each of the opposite ends, about which the element has substantially rotational symmetry.

With reference to Fig. 1, an example cylindrical roller bearing assembly may comprise a plurality of right cylindrical roller elements 10 and a pair of annular race elements 20, 30, capable of being arranged concentrically and between which the roller elements 10 are capable of rolling in use. The roller elements 10 may be separated from each other by respective retainers 40 (which may also be referred to as cages or separators). Inner and outer race elements 20, 30 comprise respective race bearing surfaces (of which the race bearing surface 32 of the outer race element 30 is visible in Fig. 1). The roller elements 10, inner race ring 20, outer race ring 30 and race bearing surface 32 being cooperatively configured such that the inner race ring 20 can rotate within the outer race ring 30 in use, the roller elements 10 rolling against the race bearing surfaces. The bearing assembly shown in Fig. 1 is an example of a radial bearing, capable of supporting a radial load.

With reference to Fig. 2A and Fig. 2B, an example taper roller bearing assembly may comprise a plurality of right cylindrical roller elements 10 arranged between a concentrically arranged pair of annular race elements 20, 30 (the outer race element 30 may also be referred to as a cup). The roller elements 10 may be separated from each other by respective retainers 40. The inner race ring 20 and outer race ring 30 may comprise respective race bearing surfaces 22, 32 against which the rollers 10 can roll in use, the race bearing surfaces 22, 32 being inclined at an angle in relation to an axis defined by the inner and outer race rings 20, 30. Each of the race rings 20, 30 has a front face 24 and a back face 26. The race bearing surface 22 of the inner race element 20 is defined by a pair of circumferential ribs, one of which is coterminous with the front face 24 and the other is coterminous with the back face 26. In use, the roller elements 10 will roll over to the race bearing surfaces 22, 32 allowing the inner and outer race elements 20, 30 to rotate relative to each other about the same axis with relatively low friction. The roller elements 10 are inclined at the relative to the axis as constrained by the race bearing surfaces 22, 32 and the bearing assembly will be capable of supporting a load having both axial AX and radial RA components.

With reference to Fig. 3, an example bearing assembly may race comprise elements 20, 30 and a plurality of roller elements 10, in which the race elements 20, 30 comprise respective race bearing surfaces that may be somewhat convex or bowed, having respective crowns 23, 33. The roller elements 10 may comprise respective bearing surfaces 12 that are somewhat convex or bowed, comprising crowns 13. Crowns 13, 23, 33 may allow greater tolerance of misalignment in the bearing assembly in use.

There are various kinds of roller bearing assembly configurations. For example, a roller bearing assembly may comprise a pair of races, between which and in contact with which the bearing elements are located and are capable of rolling in use. A roller bearing assembly may comprise a plurality of cages, each configured for housing a respective roller element, which may contribute to reducing friction and wear by preventing the bearing elements from contacting each other.

Tapered roller bearing assemblies may comprise conical roller elements that run on conical races, and will generally be capable of supporting relatively high loads having both axial and radial components. Tapered roller bearing assemblies may be suitable for use in applications where the load on the bearing assembly has both radial and axial components, particularly where the axial thrust load is relatively high and the radial load is moderate to high. Spherical roller bearings comprise an outer ring with a spherically concave inner surface, the roller elements generally being thicker in the middle and thinner at the ends. Rotary rolling bearing assemblies generally comprise a shaft located within a cylindrical housing, the shaft being spaced radially apart from the housing, and a plurality of roller elements located tightly between the shaft and the housing, the assembly configured such that the shaft can rotate within the housing (about a longitudinal axis defined by the shaft), the bearing elements rolling between the shaft and the housing to permit the relative rotation while maintaining the space between the shaft and the housing.

Various examples of roller bearing assemblies are illustrated in Fig. 4A to Fig. 4F, in which roller elements 10 are arranged between first and second race elements 20, 30.

With reference to Fig. 5, an example roller element 10 may comprise a core substrate 16 comprising cemented carbide material and having a generally cylindrical side boundary, to which may be bonded a super-hard layer 14 comprising polycrystalline diamond (PCD) material. The super-hard layer 14 may extend substantially over the entire side boundary of the core substrate 16 and be coterminous with a generally cylindrical or conical roller bearing surface 12.

With reference to Fig. 6, an example race element 20 of a bearing assembly may comprise a super-hard liner structure, which in this particular example comprises a diamond layer 27 attached to an SCD sub-structure 25, consisting of SCD material. The diamond layer 27 is coterminous with the race bearing surface 22, which will likely enhance the wear resistance and reduce friction between the roller element (not shown in Fig. 6) and the race bearing surface 22.

With reference to Fig. 7, an example roller cone bit may comprise a bit head 50 having a threaded member 54 at one end for attachment to a drill string (not shown), and three legs 52 extending from the opposite end. The shape of the drill bit defines a longitudinal axis A about which the bit head 50 will be driven to rotate in use, and which will be generally aligned with the hole being bored. Each leg 52 may comprise a respective bearing shaft 20 (which may also be referred to a journal or bearing pin) projecting inwards at an angle towards the axis A, and a respective cutter cone 30 rotatably coupled to the bearing shaft

20 by means of a roller bearing assembly comprising a plurality of roller elements 10. The bearing shaft 20 and the cutter cone 30 function as race elements of the bearing assembly comprised in the drill bit. The roller elements 10 are arranged circumferentially between a part of the cutter cone 30 and the bearing shaft 20, such that they roll about the bearing pin 20 when the cutter cone 30 rotates about the bearing pin as in use. Inner and outer race bearing surfaces may be provided as circumferential recesses formed in the cutter cone 30 and bearing shaft 20, constraining the rolling motion of the bearing elements 10 in use. A plurality of cutter members 56 are arranged as projections extending from on the outer surface of the cutter cone 30, and will be cyclically urged against the formation being drilled (not shown) to crush it.

The bit body 50, legs 52, bearing shafts 20 and cutter cones 30 are configured such that when the cutter cones 30 are contacted (via the cutter members 56) with a formation to be drilled and the bit body 50 is driven to rotate about the longitudinal axis A, each of the cutter cones 30 will be driven to rotate about its respective bearing shaft 20. In use, the cutter members 56 will repeatedly engage and disengage the formation, responsive to the rotation of the cutter cones 30 and a load applied onto the bit. Additional bearing assemblies, which may comprise ball bearing elements 60, may also be provided between the cutter cone 30 and bearing shaft 20. The frictional forces between, and the mechanical wear rates of, the cutter cone 30 and the bearing shaft 20, are thus reduced, both radial and axial components of applied load being supported by the bearing elements 10. In some examples, the race bearing surfaces on the cutter cone 30 and or the bearing shaft 20 may also comprise super-hard material such as PCD or SCD material, which may be coated with a synthetic diamond or diamond-like carbon (DLC) layer.

An example method of making an example roller element may include providing a precursor body comprising an elongate, generally annular PCD layer joined to a circumferential side boundary of a cemented carbide core body, and processing the precursor body to final dimensions and surface finish. Example methods of making precursor bodies from which roller elements according to this disclosure can be made are disclosed in international patent application publication number WO2011/157667. Some processing of the precursor bodies will likely be required to achieve the desired shape and dimensional tolerances. Examples of such processing may include of centre-less grinding, electro discharge machining (EDM), plunge machining and diamond polishing.

Example arrangements of constructions suitable for use as precursor bodies for roller elements may comprise a PCD layer joined to a side surface of a core substrate consisting of cemented tungsten carbide. In a particular example arrangement, a cylindrical core substrate having a diameter of about 8 millimetres and a pair of radially extending peripheral end structures, each at an opposite end and having diameter of about 12.5 millimetres. In some examples, the super-hard structure may be joined to the cemented carbide substrate by means of three intermediate layers between the super-hard structure and the substrate. The intermediate layers may comprise grains of tungsten carbide and grains of a super-hard material dispersed in a matrix comprising cobalt. The content of the cobalt in intermediate layer is less than that in layer, which is less than that in layer. Each intermediate layer may be at least about 0.2 millimetres thick and at most about 0.3 millimetres thick.

The precursor body may be made by sintering an aggregation of diamond grains together and to the core substrate at an ultra-high pressure of at least about 5.5 gigapascals and a temperature sufficiently high to melt the cement material, which may comprise cobalt and the temperature may be at least about 1,200 degrees Celsius.

The aggregation of diamond grains may be provided in the form of a plurality of sheets, each comprising diamond grains having a mean size of at least about 0.1 micron and at most about 30 microns held together by an organic binder. At least some of the sheets may also comprise tungsten carbide grains. The sheets may be made by a method known in the art, such as extrusion or tape casting methods, wherein slurry comprising diamond grains and a binder material is laid onto a surface and allowed to dry. Other methods for making diamond-bearing sheets may also be used, such as described in United States patents numbers 5,766,394 and 6,446,740. In some examples, the aggregation may comprise a mixture of diamond grains and catalyst material for diamond such as Co, Ni, Fe, Mn, which may be combined together by means of milling (e.g. ball billing), and cast into sheets using a plasticizer binder material such as PMMA, DBP and so forth.

The sheets comprising the diamond grains may be cut to size to fit around the core substrate and a pre-sinter assembly may be constructed by wrapping the sheets around the core substrate. In some examples, opposite edges of the sheets may be exposed at the distal end, or opposite edges of the sheets may abut respective spacer structures at opposite ends of the substrate. In some example arrangements, sheets containing both diamond grains and tungsten carbide grains may be placed against the core substrate and sheets free of tungsten carbide grains may be placed remote from the core substrate, the carbide-containing sheets thus being disposed intermediate the core substrate and the non-carbide containing sheets. Once sintered, these intermediate sheets may help reduce stress between the PCD structure and the core body since certain of their properties will be intermediate those of PCD and cemented carbide material.

In some examples the sheets may be shredded to provide a plurality of plate-like granules, or granules may be provided by other means, and the granules may be compacted together against the side surface of the substrate to form the aggregation. In some examples the method may include providing slurry comprising the super-hard grains and making the aggregation by injection moulding the slurry.

Alternative methods for depositing diamond-bearing layers include spraying methods, such as thermal spraying.

A pre-sinter assembly may comprise a cylindrical substrate, an aggregation comprising a plurality of super-hard grains arranged circumferentially around a side surface of the substrate, and a pair of spacer structures, each extending radially from opposite ends of the core body. The pre-sinter assembly may be inserted into the cavity of a vessel for insertion into a chamber of a belt-type ultra-high pressure furnace, the vessel comprising a generally cylindrical tube having a cylindrical cavity for containing a pre-sinter assembly and defining a longitudinal axis. The cavity may have opposite ends connected by a cavity wall and discs may be provided at each end of the tube to close the cavity at the respective ends. The tube and the discs may comprise pyrophyllite. The vessel and the substrate may be substantially longitudinally aligned and the spacer structure arranged between the side surface of the core body of the substrate and the cavity wall.

In some example arrangements, the pre-sinter assembly may comprise the core substrate, the aggregation and the spacer structure encased within a metal container, which may for example comprise refractory metal such as niobium, tantalum or molybdenum, having melting point of at least about 1,480 degrees Celsius. The vessel may comprise an outer tube and a concentric inner tube abutting the outer tube, the inner tube defining a cylindrical cavity of the vessel for accommodating the pre-sinter assembly.

The inner tube may comprise material capable of transmitting pressure at the high temperature, such as sodium chloride or certain other salts. The pre-sinter assembly may be inserted into the cavity defined by the inner tube such that the peripheral outer surface of the metal container abuts the inner surface of the inner tube (i.e. the cavity wall). In such example arrangements, part of the metal container will be disposed between the spacer structure contained within it and the cavity wall.

In some examples, the aggregation of diamond grains may be sintered in the presence of the cobalt comprised in the substrate by heating the pre-sinter assembly to a temperature sufficient to melt the cobalt, causing some of the cobalt to infiltrate into the aggregation, and applying an ultra-high pressure of at least about 5.5 gigapascals to the pre-sinter assembly. In some examples, the aggregation may contain cobalt or other catalyst material for diamond. The pressure may be generated by applying sufficiently large opposing longitudinal forces to the pre-sinter assembly via the discs. Heat may be applied by passing an electrical current through the assembly and heater elements may be provided in the assembly, including possibly in the pre-sinter assembly or this purpose. The spacer structure will provide some lateral support for the substrate.

In some example arrangements the substrate may comprise an elongate core body and an end structure at one end. The end structure may extend a distance radially from the core body, configured around the core body to function as a spacer structure according to this disclosure. In some example arrangements the spacer structure may comprise a ring arranged around the substrate, or the spacer structure may comprise a disc arranged at an end of the substrate.

In other example variants of the method, the core body may be placed within a container such as cup configured so that the inner wall of the container is substantially dimensioned to correspond to the shape and dimension of the side surface of the end formation, and substantially loose super-hard grains may be poured into the gap thus formed between the central column and the inner wall of the container. An amount of plasticiser and or binder material and or catalyst material for sintering the super-hard grains may also be introduced into the aggregation in this way, and the aggregation may be compacted. The container may form part of the pre-sinter assembly.

The pre-sinter assembly may be assembled into a capsule for an ultra-high pressure furnace (or press), heated in a furnace to remove volatile gasses and or burn off binder material, and subjected to a pressure of at least about 5 gigapascals and a temperature of at least about 1,300 degrees Celsius, and the diamond grains sintered together to form a sintered construction comprising a generally tube-like PCD structure joined to a core body and enclosing the central column of the core body. Cobalt for promoting the sintering of the diamond and for cementing the grains of the intermediate layer or layers may be sourced from the cemented carbide substrate.

After the sintering process at the ultra-high pressure, the sintered construction can be recovered from the ultra-high pressure apparatus and capsule material removed from it.

In some examples the super-hard grains are cBN grains and the super-hard structure may comprise PCBN material. In such examples, the aggregation may comprise a mixture of boron nitride powder with a binder material containing Ti, Al, W or Co and the mixture cast into sheets using a plasticizer material.

One version of an example method may include providing a cemented carbide substrate having a shaped, elongate proximate end portion defining a support surface; providing a super-hard structure having a join surface configured to have a shape complementary to that of the support surface and joining the join surface of the super-hard structure to the support surface of the substrate.

Roller elements and or one or more races may comprise SCD material. Articles comprising SCD material may be manufactured at relatively low pressures at which diamond is less thermodynamically stable then graphite, such as at pressures of less than about 1 kilobar. This may permit relatively large articles to be made and or for the articles to have relatively more complex shapes than may be commercially viable for PCD articles. For example, guide means for roller elements may comprise continuous monolithic rings, cylindrical sections and or arcuate sections comprising SCD material.

Examples of SCD materials and methods of making structures comprising SCD material are described in United States patents numbers 7,008,672; 6,709,747; 6,179,886; 6,447,852; and international patent application publication number WO2009/013713, for example. A liner structure comprising SCD material may be made by providing a suitable mould for the structure or the sub-structures of which the liner structure may be comprised. Grooves may be provided in the liner structure or sub-structures by suitable configuration of the mould or by machining the grooves after the SCD material has been sintered.

A liner structure comprising SCD material may be made by an example method including combining and compacting a plurality of diamond grains with a small amount of organic binder material to provide a so-called “green body”, being a self-supporting un-sintered structure comprising a plurality of small grains. The size distribution of the diamond grains may selected such that the volume content of the diamond grains in the sintered SCD material may be high or optimised, smaller grains being dispersed in the interstices between larger grains. The green body may be formed by methods including compaction pressing, slip casting, slurry casting or injection moulding, some of which may require the green body to be formed in a mould, from which it will be removed. The green body may be processed by machining to provide a desired shape. If the green body contains binder material, it may be subject to heat treatment in suitable atmosphere to decompose, evaporate, harden or remove the binder material so that the content of binder material is at most about 5 weight per cent of the green body, the balance being diamond grains. An intermediate body may be provided by introducing non-diamond carbon onto the surfaces of the diamond grains, for example by heating the green body to convert at least some of the diamond at the surface of the grains into a thin layer of graphite, and or by depositing pyrolytic carbon onto the surfaces of the diamond grains. A source of high purity silicon may then be placed against the intermediate body to provide an infiltration assembly, which may be placed in a graphite tray and heated in an inert atmosphere to a temperature sufficiently high to melt the silicon. The molten silicon will infiltrate into the voids between the diamond grains of the intermediate body and react with the non-diamond carbon provided on the surfaces of the diamond grains, resulting in the formation of a silicon carbide matrix to which the diamond grains are chemically bonded. It is likely that a minor amount of the infiltrated silicon may not react to form silicon carbide and may remain in elemental (non-compound form). The resulting sintered article will have a desired shape and comprise a plurality of diamond grains present at relatively high content, chemically bonded in a matrix comprising mostly silicon carbide. The sintered article may be machined to final dimensions to provide the liner structure or sub-structure.

A thin layer of steel or other metal material, for example having a thickness of about 0.2 millimetres, may be provided on at least the part of the liner structure to be attached to a support body by means of braze alloy. This may be achieved by placing a film of the metal material over the relevant part and subjecting it to cold isostatic pressing (CIP) to join the metallic film to a surface of the SCD material. Provided that the metal material of the joined film is suitably selected, its presence may permit the liner structure or sub-structures to be joined to the base body by means of brazing, in which braze alloy material is positioned between the metal layer and the base body, melted by heating and then cooled to solidify and form a bonding layer.

Diamond layers can be deposited onto surfaces comprising SCD material by a process of chemical vapour deposition (CVD), in which the surface is heated to a temperature of at least about 400 degrees Celsius or at least about 700 degrees Celsius and at most about 1,100 degrees Celsius in the presence of methane and hydrogen gas heated to a temperature of about 2,000 degrees Celsius. Carbon from the methane may thus be deposited in the form of diamond onto the surface. In one version of the process, the gas is heated by means of a hot filament (hot filament CVD, or HFCVD). Areas of the liner structure or sub-structure not to be coated with a diamond layer can be masked by suitable means during this process. The diamond layer may increase the wear resistance and reduce the friction of the race bearing surface, since while The Knoop hardness of SCD material may be of the order of about 40 gigapascals, that of CVD deposited diamond material may be in the range of about 85 to 100 gigapascals.

Roller bearings according to this disclosure are likely to have the aspect low friction torque characteristics and to be suitable for relatively high speed operation.

The effect of both the race element and the roller elements comprising super-hard material such as diamond material, configured such that the super-hard material comprised in each is coterminous with respective bearing, is expected to be synergistic, since the friction and degradation due to sliding wear will be relatively low, which will likely enhance the operational efficiency and working life of the bearing assembly.

Particularly when the bearing assembly operates at high speed and or in high temperature environments, it will likely be desirable for the components of the roller bearing assembly to exhibit as little thermal expansion as possible. Bearing assemblies comprising any of

PCD, SCD and or CVD deposited diamond material (or combinations of any of these materials) according to example arrangements according to this disclosure will likely be suitable for such applications. For example, roller bearing assemblies in which the roller elements comprise PCD material and the race bearing surface comprises SCD material coated with a layer of CVD deposited diamond, and configured such that the PCD material will contact the diamond layer of the race bearing surface in use will likely be suitable for such applications.

In general, one or more elements of the roller bearing assembly, such as the roller elements and or race element and or liner structure, may comprise a diamond layer joined to a substrate comprising or consisting of SCD material. While wishing not to be bound by a particular theory, the adherence may result at least partly from a combination of homo-epitaxial growth of the layer on diamond grains exposed at the surface of the CVD material and hetero-epitaxial growth of the layer on the silicon carbide matrix between the diamond grains. It may be expected that the relatively high value of the elastic modulus and the relatively low coefficient of linear expansion of SCD material, which are relatively closely matched with the properties of the CVD deposited diamond layer, may provide a race bearing surface having enhanced thermo-mechanical properties. The coefficient of linear thermal expansion of such a composite construction at about 25 degrees Celsius is approximately 1.8 X 10^{-6} /K (1.8 times ten to the power of minus six, per Kelvin) to about 4.4 X 10^{-6} /K (4.4 times ten to the power of minus six, per Kelvin). The coefficient of linear thermal expansion of high carbon steel at about 25 degrees Celsius is approximately 17 X 10^{-6} /K.

Example arrangements may comprise a first element, for example a roller element, comprising PCD material coterminous with a first bearing surface, and a second element, for example a liner structure of a race element, comprising SCD material coterminous with a second bearing surface, in which the first bearing surface contacts the second bearing surface and rolls against it in use. Such example arrangements are likely to have the aspect that the coefficient of friction between the PCD material and the SCD material will be relatively low, in the range of about 0.05 to about 0.1, for example. If the SCD material is coated with a layer of diamond, by means of CVD for example, then the coefficient of friction is expected to be even lower, in the range of about 0.01 to about 0.05, for example. By contrast, the coefficient of friction between high carbon chromed steels race bearing surfaces running against high carbon chrome coated steel roller bearings is expected to be in the range of about 0.4 to about 0.7.

Tapered bearing assemblies comprising cylindrical and tapered bearing elements according to this disclosure have the aspect that loads having both axial and radial components can be supported. Convergently-urged bodies (in other words, bodies that are being forced towards each other in relative terms) can be moveably coupled to each other by means of a bearing assembly according to this disclosure, which is likely to have the aspect of reduced frictional force opposing the relative movement of the bodies and or reduced abrasive or other wear of bearing components. The relative movement of the bodies may be rotational or translational, for example.

In examples where the super-hard material comprises diamond, particularly in proximity to or contact with solvent / catalyst material for diamond, reduced friction and consequent heating may have the aspect of reducing potential thermal degradation of the diamond. This is expected to pose an increased risk at relatively high operating speeds of the bearing assembly. A further risk potentially arises from the thermal expansion of components and their consequent deformation and misalignment, which likely reduce the efficiency of the bearing assembly.

While wishing not to be bound by a particular theory, the solvent / catalyst material (generally metal material comprising one or more of cobalt, iron, nickel or manganese) contained within the surface region of the PCD material may migrate to the bearing surface and or escape from the surface region of the bearing surface in certain operations. This may occur as a consequence of the mechanical rolling action at the interface with the race bearing surface or of heat accumulation within the roller element. This escaped material may form a tribological film at the interface of the bearing surface and the race bearing surface, which will likely increase the friction and reduce the efficiency of the bearing operation. Furthermore, the presence of solvent / catalyst material for diamond within the PCD material, particularly within the surface region, may result in thermal degradation of the PCD material if the latter is subjected to high temperature in use (or manufacture). This may occur as a result of the difference in the thermal expansion response of the diamond and the solvent / catalyst material, and or as a result of the promotion of the conversion of some of the diamond into graphite by the solvent / catalyst material. The latter process will likely be particularly significant if the temperature of the PCD material reaches about 700 degrees Celsius or higher. SCD material and CVD deposited diamond material do not generally contain solvent / catalyst material for diamond. Difficulties associated with processes describe above will likely be ameliorated in example arrangements in which at least a surface region of a super-hard structure comprising diamond material, coterminous with a bearing surface contains a relatively small amount of solvent / catalyst material for diamond, or substantially no solvent / catalyst material for diamond.

Certain example arrangements of bearing assemblies may be capable of supporting loads having both radial (or lateral) and axial (or longitudinal) components. Certain roller bearing assemblies are generally expected to combine high thrust capacity with low friction and accommodate shaft deflection which may occur as a consequence of high axial thrust loading.

Non-limiting examples are described below in more detail.

Example 1

An annular precursor body construction for making a PCD roller element can be manufactured as follows.

An aggregation comprising diamond particles having a mean size of at least about 1 micron and at most about 15 microns can be prepared by blending the diamond particles with powder comprising cobalt catalyst material for diamond. Plasticiser material such as PMMA or DBP can be introduced into the blend in order to make a slurry that is sufficiently viscous that it can be cast. The blending can be achieved by means of a ball mill. The slurry can be cast into a sheet, which can be dried and shredded to provide a plurality of plate-like granules.

A cylindrically shaped cobalt-cemented tungsten carbide rod having diameter of about 8 mm can be provided. The rod, which will function as a core substrate for an annular PCD structure, can be placed concentrically within a cylindrical die for compacting powder, the diameter of the die being 12.5 mm. A first cemented carbide spacer ring having thickness of about 1 mm can be placed around the rod between the rod and the die wall at the bottom of the die, abutting the rod and the die wall to maintain the position of the rod. The diamond-containing granules can be poured into the space between the rod and the wall of the die and repeatedly compacted by means of an annular press device configured to fit between the rod and the die. When the space is filled with partially compacted granules, a second cemented carbide spacer ring can be placed around the rod at the top end on the die, above the granules. The inner diameter of the second spacer ring should be slightly larger, by about 0.05 mm, than the diameter of the rod so that the second spacer ring can slide down the rod when subjected to the ultra-high pressure during the sintering step, which is described below. This will reduce the risk of non-uniform compaction of the aggregation and the formation of non-planar ends of the construction. The second spacer ring can be made of ceramic or metal alloy material having high creep resistance at temperatures of at least about 900 degrees Celsius.

The annular press device can be applied to the second (top) spacer ring, a load can be applied to the press device and the granules can be compacted to provide a dense green body aggregation (i.e. a shaped and compacted aggregation still comprising the plasticiser) having an annular shape and surrounding the rod. After compaction, the assembly comprising the rod, green body aggregation and spacer rings at opposite ends of the rod can be removed and placed within a cup made of refractory metal. The assembly can be heat treated in a vacuum at about 1,050 degrees Celsius in order to remove plasticiser binder material by outgassing. A second cup made of the refractory metal can then be placed over the uncapped end of the assembly such that the pair of opposite cups overlap each other, thus completely encasing the assembly to provide a complete pre-sinter assembly. The pair of cups are welded together around the circumference of the pre-sinter assembly where the cups overlap, by means of an electron beam welding apparatus. In other examples, the pre-sinter assembly may be isostatically compressed to join the cups mechanically.

The pre-sinter assembly can then be assembled into a capsule for a belt-type ultra-high pressure press. The capsule may comprise an outer tube comprising pyrophyllite and an inner tube comprising sodium chloride salt, the pre-sinter assembly being inserted into the inner tube such that the outer side surface of the metal encasement abuts the inner surface of the inner tube. The per-sinter assembly can be subject to an ultra-high pressure of about 5.5 GPa and a temperature of about 1,300 degrees Celsius for a sufficiently long period for the cobalt in the substrate and in the aggregation to melt and the diamond grains of the aggregation to inter-grow with each other to form a PCD annulus joined to a cemented carbide core. The pressure and temperature can be reduced to ambient conditions and the capsule and metal cupping material removed by sand blasting and or acid treatment to provide a construction comprising a PCD structure surrounding the carbide rod, to opposite ends of which the carbide rings are joined.

The construction can be processed to final dimensions and tolerances to provide a roller element for a roller bearing assembly.

Example 2

An PCBN annular precursor body can be manufactured analogously to a PCD blank body substantially as described in Example 1, except that the aggregation will comprise cBN particles instead of diamond particles and they will be combined with powder comprising Ti, Al, W and or Co for making binder material for the cBN grains. The size distribution of the cBN particles may be at least about 0.5 micron and at most about 10 microns.

Example 3

A precursor structure for a PCD layer may be made by preparing a sheet comprising diamond grains held together by a water-based organic binder. The sheet may be about 500 microns in thickness and comprise diamond grains having a mean size in the range from about 5 microns to about 15 microns, and may be made by means of tape casting. This would involve preparing slurry comprising diamond grains and an organic binder being cast onto a belt and dried to remove the binder solvent. The content of the diamond grains in the sheet should be at least about 50 volume per cent of the sheet. About six strips may be cut from the sheet, the strips each having a slightly different length such that they may be stacked upon one another sequentially, starting with the shortest strip and ending with the longest strip, and wrapped around the recess portion of the substrate adjacent the proximate end with the shortest strip in contact with the substrate. The respective lengths of the strips should be just sufficient for the ends of each strip to touch each other when wrapped around the substrate, depending on the respective position of the strip in the stack. The width of the strips should be substantially the same as each other and equal to the width of the recess portion.

A pre-sinter assembly may thus be formed, comprising a substantially co-axial tubular arrangement of a plurality of wrapped strips containing diamond grains. The pre-sinter assembly may be encapsulated into a capsule for an ultra-high pressure furnace and subjected to a pressure of at least about 5 gigapascals and a temperature of at least about 1,300 degrees Celsius, at which diamond grains in the presence of cobalt may sinter together. The cobalt may be sourced from the substrate during the ultra-high pressure, high temperature treatment. The resulting component would comprise a tube of sintered PCD material integrally bonded co-axially at the end of a carbide substrate cylinder.

The sintered component may then be processed to final dimensions and surface finish to provide a roller element for a roller bearing assembly. For example, processing may include electro-discharge machining and or mechanical diamond grinding.

Certain terms as used in this disclosure are briefly explained below.

A bearing or bearing assembly is a mechanism for moveably coupling parts of a mechanical system, such that relative movement of the parts is constrained and friction is reduced. In some mechanical systems, at least part of the bearing assembly may be under compressive force in use, the coupled parts being urged generally towards each other. The coupled parts may be coupled such they can rotate, translate or reciprocate relative to each other in use. Roller bearing assemblies comprise roller elements, which may also be referred to as “rollers”, configured to be capable of rolling (each about its own axis) race elements moving relative to each other.

As used herein, a bearing surface is an area for or of contact (in the assembled or in a partly assembled condition) between two elements of a bearing assembly.

Synthetic and natural diamond, polycrystalline diamond (PCD), cubic boron nitride (cBN), polycrystalline cBN (PCBN), and silicon-carbide bonded diamond (SCD) material are examples of super-hard materials. As used herein, synthetic diamond, which is also called man-made diamond, is diamond material that has been manufactured. As used herein, polycrystalline diamond (PCD) material comprises an aggregation of a plurality of diamond grains, a substantial portion of which are directly inter-bonded with each other and in which the content of diamond is at least about 80 volume per cent of the PCD material. Interstices between the diamond grains may be at least partly filled with a filler material that may comprise solvent / catalyst material for synthetic diamond, or they may be substantially empty. As used herein, a solvent / catalyst material for synthetic diamond is capable of promoting the growth of synthetic diamond grains and or the direct inter-growth of synthetic or natural diamond grains at a temperature and pressure at which synthetic or natural diamond is thermodynamically stable. Examples of solvent / catalyst materials for diamond are Fe, Ni, Co and Mn, and certain alloys including these. Bodies comprising PCD material may comprise at least a region from which catalyst material has been removed from the interstices, leaving interstitial voids between the diamond grains.

As used herein, PCBN material comprises grains of cubic boron nitride (cBN) dispersed within a matrix comprising metal or ceramic material.

Other examples of super-hard materials include certain composite materials comprising diamond or cBN grains held together by a matrix comprising ceramic material, such as silicon carbide (SiC), or cemented carbide material, such as Co-bonded WC material (for example, as described in United States patents numbers 5,453,105 or 6,919,040). For example, certain SiC-bonded diamond materials may comprise at least about 30 volume per cent diamond grains dispersed in a SiC matrix (which may contain a minor amount of Si in a form other than SiC).

CLAIMS

1. A roller bearing assembly comprising: (a) a roller element comprising a roller bearing surface defined by a super-hard structure; and (b) a race element comprising a race bearing surface; wherein the race element and the roller element are configured such that the roller element can roll through at least one complete revolution about an axis of rolling rotation, throughout which rolling movement the roller bearing surface abuts the race bearing surface, and the super-hard structure is configured such that the roller element is capable of supporting a load of at least 4,500 Newtons applied onto the roller bearing surface.

2. A roller bearing assembly as claimed in claim 1, in which the roller bearing is configured such that the roller bearing surface will appear circular when viewed in a cross section perpendicular to an axis of rolling rotation, the diameter of the cross sectional circle being at least 2.5 millimetres and at most about 70 millimetres, and the roller bearing surface having a radial dimensional variation of at most about 5 microns.

3. A roller bearing assembly as claimed in claim 1 or 2, in which the super-hard structure comprises a plurality of contiguous super-hard sub-structures, at least one of which is coterminous with the roller bearing surface.

4. A roller bearing assembly as claimed in any of the preceding claims, in which the super-hard structure comprises a material selected from the group consisting of cubic boron nitride (cBN) material, polycrystalline diamond (PCD) material, polycrystalline cubic boron nitride (PCBN) material, silicon carbide bonded diamond (SCD) material, and diamond film.

5. A roller bearing assembly as claimed in any of the preceding claims, in which the super-hard structure comprises PCD material and at least a surface region of the PCD material coterminous with the roller bearing surface is substantially devoid of solvent / catalyst material for diamond.

6. A roller bearing assembly as claimed in any of the preceding claims, in which at least a surface region of the super-hard structure coterminous with the roller bearing surface contains a plurality of voids.

7. A roller bearing assembly as claimed in any of the preceding claims, in which the super-hard structure comprises super-hard material extending a depth of at least 0.5 millimetres from the roller bearing surface.

8. A roller bearing assembly as as claimed in any of the preceding claims, in which the super-hard structure is attached to a substrate at an interface boundary connecting a pair of opposite ends of the substrate, arranged such that the super-hard structure is co-axial with the substrate.

9. A roller bearing assembly as claimed in any of the preceding claims, in which the super-hard structure is attached to a substrate and the substrate comprises an intermediate volume and a core volume comprising cemented carbide material, the intermediate volume being coterminous with the core volume and the interface boundary; the intermediate region comprising material having a coefficient of thermal expansion (CTE) at 25 degrees Celsius of greater than that of the super-hard structure and less than that of the cemented carbide material.

10. A roller bearing assembly as claimed in any of the preceding claims, in which the super-hard structure is in the form of a layer having a thickness of at least 0.5 millimetres and at most about 5 millimetres.

11. A roller bearing assembly as claimed in any of the preceding claims, in which the race element comprises a liner structure attached to a support body, the liner structure having higher resistance to abrasive wear than the support body; the liner structure and the support body arranged such that a surface of the liner structure is coterminous with the race bearing surface.

12. A roller bearing assembly as claimed in claim 11, in which the liner structure comprises one of the following: silicon carbide material; SCD material; diamond film; and diamond film joined to SCD material; the silicon carbide material, SCD material and diamond film, when used, being coterminous with the race bearing

surface, and the diamond film joined to SCD material, when used, being arranged such that the surface of the diamond film is coterminous with the race bearing surface.

13. A roller bearing assembly as claimed in claim 11 or 12, in which the liner structure comprises a plurality of liner sub-structures, configured to be capable of being attached to the support body contiguously with each other.

14. A roller element for a roller bearing assembly as claimed in any of the preceding claims, the roller element comprising a super-hard structure defining a roller bearing surface and configured operable to roll against a body through at least one complete revolution about an axis of rolling rotation, the roller bearing surface abutting the body throughout the revolution, the super-hard-structure being configured such that the roller element is capable of supporting a load of at least 4,500 Newtons applied onto the roller bearing surface.

15. A method of making a roller element for a roller bearing assembly, the method including providing a precursor body comprising an elongate, generally annular super-hard layer joined to a circumferential side surface of a cemented carbide core substrate, and processing the precursor body to final dimensions and surface finish.

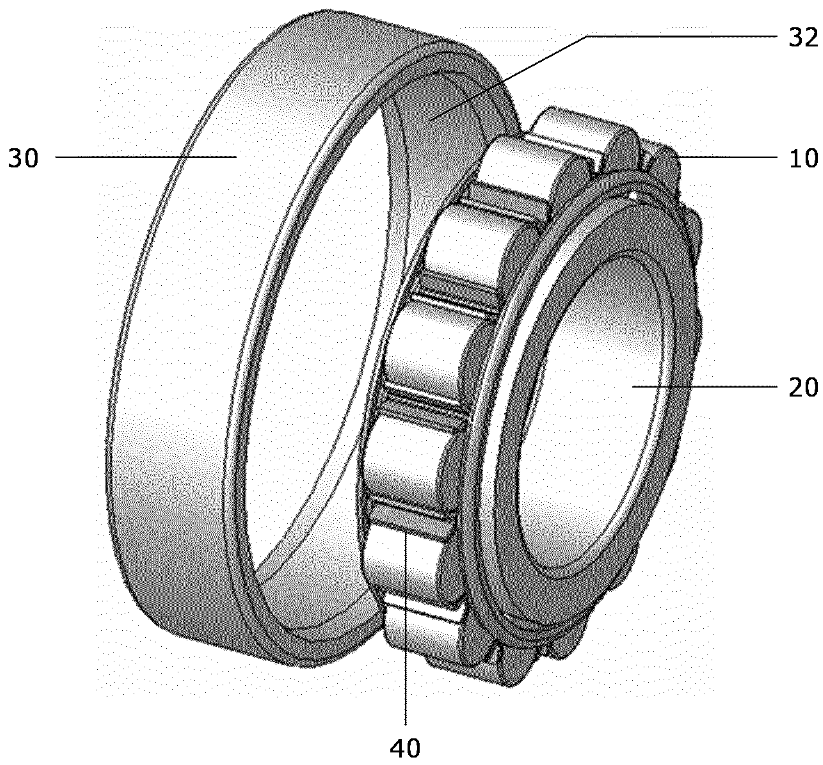

Fig. 1

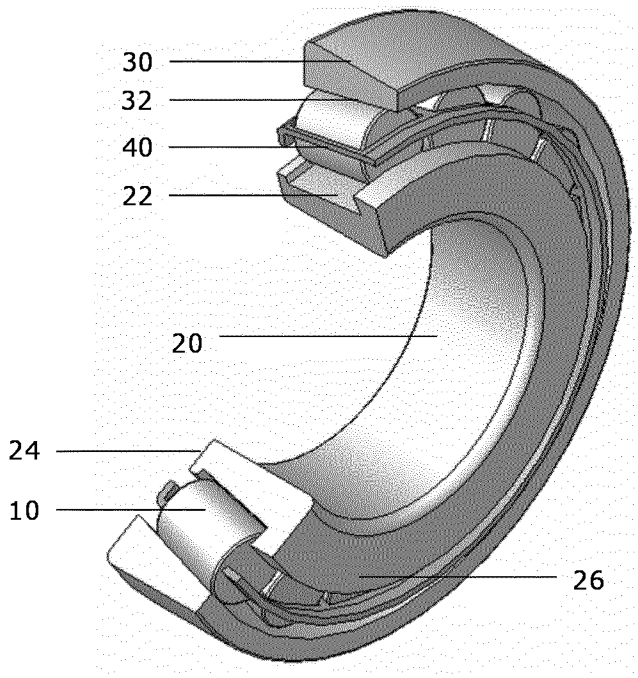

Fig. 2A

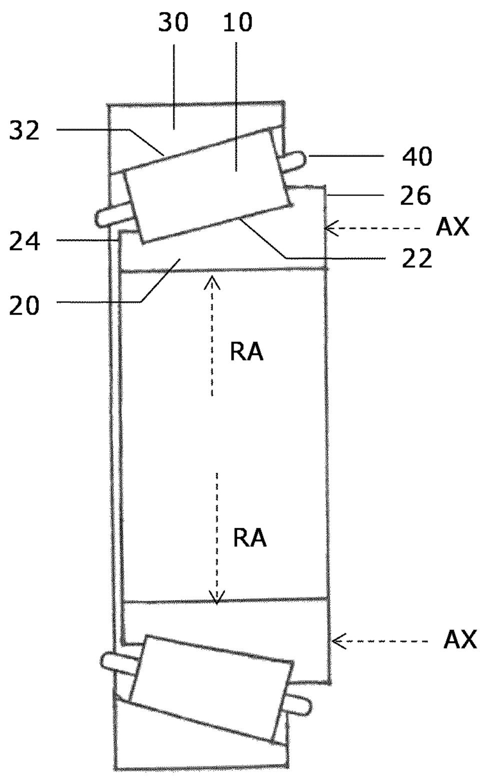

Fig. 2B

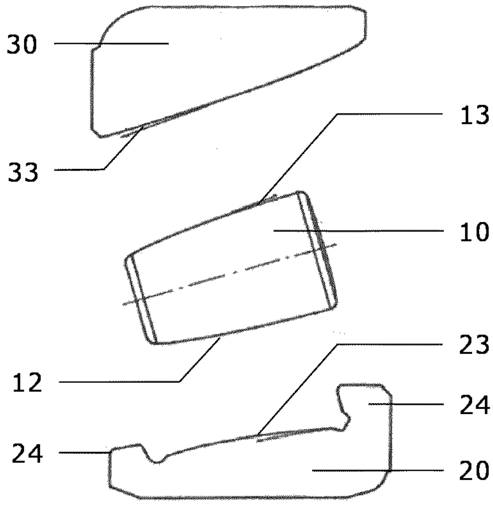

Fig. 3

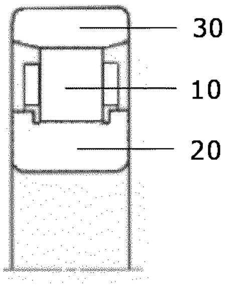

Fig. 4A

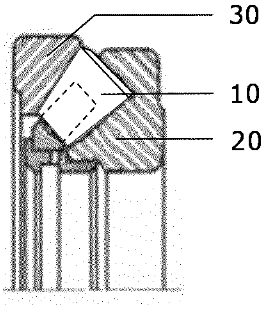

Fig. 4B

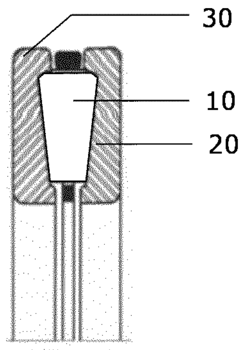

Fig. 4C

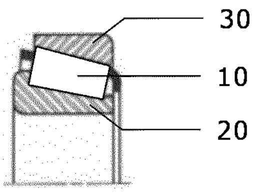

Fig. 4D

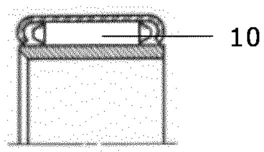

Fig. 4E

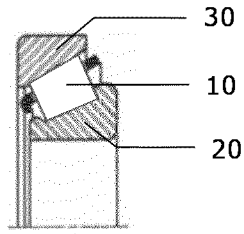

Fig. 4F

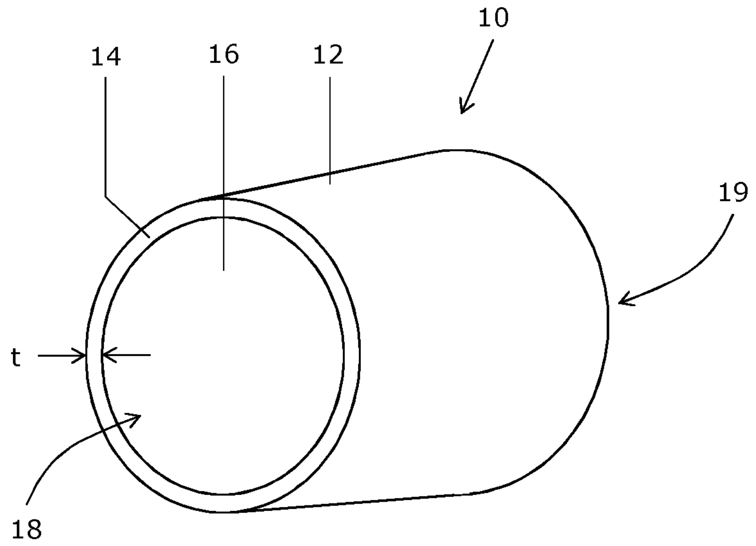

Fig. 5

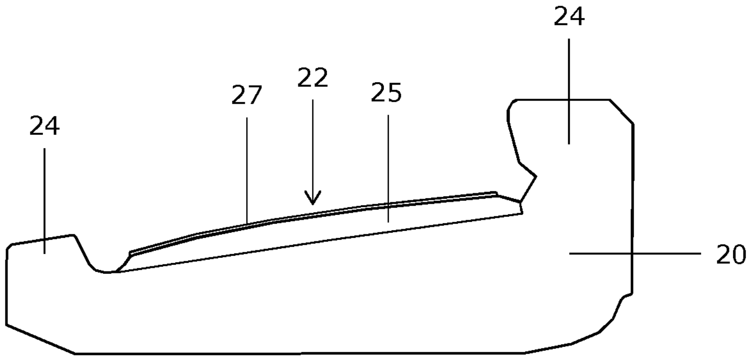

Fig. 6

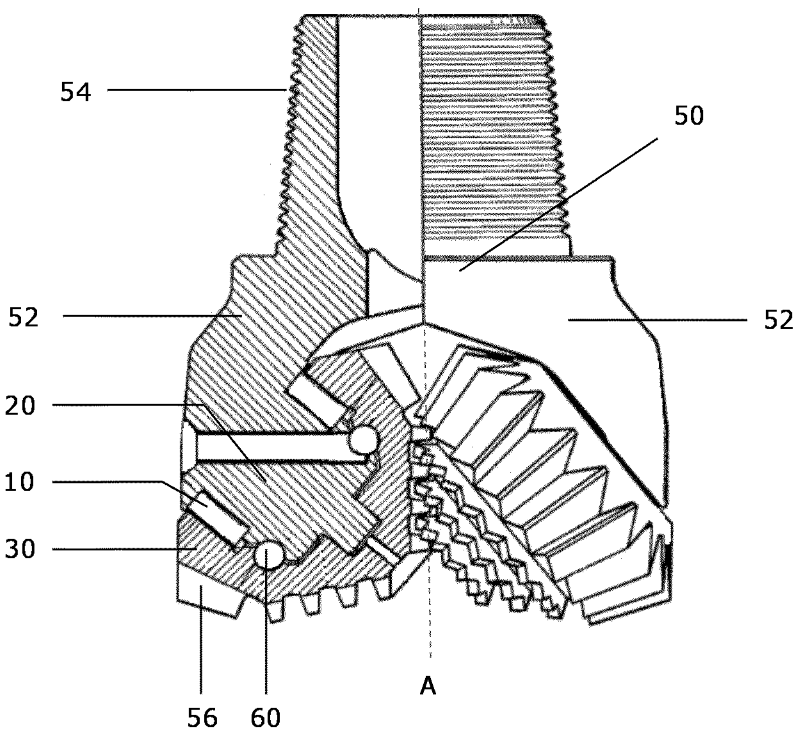

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/054565

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16C33/64 F16C33/58 F16C33/34 F16C33/62 F16C19/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 655 845 B1 (POPE BILL J [US] ET AL) 2 December 2003 (2003-12-02) cited in the application	1-10,14, 15
Y	column 3, line 30 - column 6, line 38; figures	11-13
Y	US 2013/042845 A1 (KENNEDY MARCUS [DE] ET AL) 21 February 2013 (2013-02-21) paragraph [0008] - paragraph [0019]; figure 1	11-13
X,P	WO 2013/112330 A1 (US SYNTHETIC CORP [US]) 1 August 2013 (2013-08-01) paragraph [0005] - paragraph [0008]; figures	1,3-10, 14,15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 2014	02/06/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Daehnhardt, Andreas

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/054565

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