METHOD

Fig. 1 B

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MILLING TOOLS, METHOD FOR MAKING SAME AND METHOD OF USING SAME

This disclosure relates generally to milling tools comprising the super-hard cutter segments, to methods for making the milling tools and methods of using them.

United States patent number 7,104,160 discloses a method of producing a cutting tool. The method includes the steps of providing an un-bonded assembly comprising a cylindrical core having ends and an elongate side surface covered partially or completely by a coherent, un-sintered layer, the layer comprising ultra-hard abrasive grains suitable for producing an ultra-hard material; subjecting the un-bonded assembly to elevated temperature and pressure conditions at which the ultra-hard abrasive is crystallographically stable, recovering the sintered product which comprises a cylindrical core and an ultra-hard abrasive material bonded to the core, and working the sintered product to produce one or more cutting edges in the ultra-hard abrasive material. The sintered product which is produced comprises a cylindrical core and an ultra-hard material bonded to the core and covering the entire elongate side surface thereof. Cutting edges can be produced by removing some of the ultra-hard material so as to produce two or more spaced ultra-hard material regions, each presenting at least one cutting edge which is preferably curved, helical or twisted.

There is a need for milling tools capable of efficiently machining relatively thick work-piece bodies.

Viewed from a first aspect, there is provided a milling tool having a longitudinal axis about which the milling tool will rotate in use, comprising an elongate tool body on which a plurality of cutter assemblies are arranged azimuthally (about the longitudinal axis), each cutter assembly comprising a plurality of super-hard cutter segments attached to the tool body in an axial arrangement (in other words, the cutter segments comprised in each cutter assembly are arranged along the tool body, the arrangement having an axial component), each cutter segment having a cutting edge; in which the tool body and the cutter segments are configured such that the cutting edges define a mean cut diameter of at least 6 (six) millimetres (mm) and a cut length of at least 1.5 times the mean cut diameter.
Each cutter assembly may be said to be a compound tooth, comprising a plurality of cutter segments.

Various example arrangements and combinations of features are envisaged for milling tools according to this disclosure, of which non-limiting, non-exhaustive examples are described below.

In some examples, the milling tool may be an end mill tool, a router tool or a reamer tool. For example, the milling tool may be a router tool for edge trimming or shaping work-piece bodies comprising composite material, such as wood composite material or carbon fibre reinforced plastic (CFRP) material. In other examples, the milling tool may be a reamer tool for enlarging the size of a previously formed hole by a small amount but with a high degree of accuracy or for removing burrs on a work-piece body comprising metal material.

In some example arrangements, the super-hard cutter segments may comprise polycrystalline diamond (PCD) material or polycrystalline cubic boron nitride (PCBN) material, or they may comprise chemical vapour deposited (CVD) diamond material. In some example arrangements, the super-hard segments may comprise super-hard grains, such as grains of diamond or cubic boron nitride (cBN) dispersed in a matrix comprising cemented carbide material or ceramic material.

In some example arrangements, a milling tool may comprise an elongate tool body having a side area extending axially between a pair of mutually opposite ends and azimuthally around a longitudinal axis defining an axis for rotation in use (which may be referred to as a spin axis).

In some example arrangements, each cutter assembly may be arranged such that the cutting edges lie along a helical path about the longitudinal axis. In various examples, the cutting edges comprised in each cutter assembly may or may not extend up to or beyond a full revolution about the tool body. In other examples, each cutter assembly may be arranged such that the cutting edges lie on a straight path that is substantially parallel to the longitudinal axis.
In some example arrangements, the milling tool may be configured such that the cutting edges are substantially equidistant from the longitudinal axis. In other example arrangements, the milling tool may be configured such that the cutting edges are at different (radial) distances from the longitudinal axis.

In some example arrangements, the cutter segments comprised in each cutter assembly may be arranged such all the cutter assemblies extend substantially the same axial distance (being the cut length), and in other examples, cutter assemblies may extend different axial distances along the cutter body (the overall cut length being the overall axial distance spanned by the cutter assemblies, taken together). In some example arrangements, the cutter assemblies may be arranged such that they each extend between substantially the same axial positions along the longitudinal axis.

In some example arrangements, the cutter assemblies may be azimuthally equidistant from each other.

In some example arrangements, the milling tool may comprise at least 3 (three), at least 4 (four) or at least 6 (six) cutter assemblies. In some example arrangements, the milling tool may comprise at most 8 (eight) or at most 6 (six) cutter assemblies. In general, the smaller the cut diameter, the fewer cutter assemblies will likely be present. In some examples, the milling tool may comprise two (2) cutter assemblies.

In some example arrangements, the cut length may be at least 2 times (twice), at least 3 (three) times or at least 5 (five) times the mean cut diameter.

In some example arrangements, the mean cut diameter may be at least 8 (eight) millimetres (mm), at least 10 (ten) mm or at least 12 (twelve) mm. In some examples, the mean cut diameter may be at most 16 millimetres (mm) or at most 12 mm.

In some examples, the cut length may be at least 9 (nine) millimetres (mm), at least 12 (twelve) mm, at least 15 (fifteen) mm or at least 18 (eighteen) mm. In some examples, the cut length may be at most about 30 (thirty) millimetres (mm).

In some example arrangements, each cutter assembly may comprise at least 2 (two), at least 3 (three) or at least 4 (four) cutter segments.
In some examples, the milling tool may comprise a plurality of bi-directional helical flutes. In some examples, a milling tool may comprise a first set of cutter assemblies and a second set of cutter assemblies, in which first and second cutter assemblies are arranged such that they have opposite chirality ("handedness", in other words). For example, the first and second sets of cutter assemblies may lie on right-handed helical and left-handed helical paths, respectively, or vice versa. Such arrangements may be referred to as bi-directional.

In some examples, the first and second sets of cutter assemblies may lie on intersecting helical paths, in which the cutter segments may appear to cross each other. Such milling tools may be de-burring tools for removing burrs from a work-piece.

In some examples, the first and second sets of cutter assemblies may be arranged on different regions of the tool holder. For example, the first set of cutter assemblies may be arranged on a first region adjacent a proximate end and the second set may be arranged on a second region remote from the proximate end and adjacent the first region. The first and second sets of cutter assemblies may not appear to cross each other, and may be substantially coterminal in some examples. The cutter assemblies may appear to form a chevron-like pattern on the tool body and be arranged in relation to the direction of rotation of the milling tool in use, such that the milling tool will be capable of putting an edge of a work-piece into compression. The milling tool may thus have an effect of compressing (in other words, squeezing) the edge of the work-piece between the cutter segments of the first and second sets of cutter assemblies.

Such a milling tool may be used for compressive routing or edge trimming operations, and may be used for routing or trimming work-pieces comprising fibrous composite material such as carbon fibre reinforced plastic (CFRP) or wood-containing composite material, or other material that may be vulnerable to tearing or chipping during a routing or edge trimming operation.

Viewed from a second aspect, there is provided a method of making a milling tool according to this disclosure, the method including providing an elongate tool body having a longitudinal axis, and a plurality of super-hard cutter segments having respective cutting edges and configured such that they can be arranged to provide the cutter assemblies; and attaching the cutter segments to the tool body, the cutter
segments (configured for each cutter assembly) being arranged axially along the tool body to provide the respective cutter assemblies; in which the tool body and the cutter segments are configured such that the cutting edges define a mean cut diameter of at least 6 (six) millimetres (mm) and a cut length of at least 1.5 times the mean cut diameter.

Many variations of the method are envisaged, non-limiting and non-exhaustive examples of which will be described.

In some example methods, the cutter segments comprised in each cutter assembly may be configured such that their cutting edges will lie on a helical path about the longitudinal axis when they are assembled as the respective cutter assemblies.

In some example arrangements, the tool body may be provided with recesses for accommodating the cutter segments.

In some example methods, each cutter segment may comprise a super-hard layer joined to a substrate comprising cemented carbide material.

In some example methods, each cutter assembly may comprise at least 2 (two) or at least 3 (three) cutter segments.

Some example methods may include providing a blank construction comprising a super-hard layer bonded to a boundary of a substrate comprising cemented carbide material, the blank construction having opposite ends connected by an azimuthally arcuate side (that is, the side will describe an arcuate surface about the longitudinal axis) at least partly defined by the super-hard layer; cutting the construction axially (in other words, in a direction having a longitudinal, length-wise component) to provide a plurality of precursor structures for the cutter segments and processing the precursor structures to provide the plurality of cutter segments.

In some examples, the arcuate side of the blank construction may be cylindrical in shape. The super-hard layer may be in the form of a tube surrounding a substantially cylindrical substrate core.
The method may include cutting the blank construction along a path having both axial and azimuthal components. For example, the blank construction may be cut along a plurality of substantially conformal helical paths to provide at least one helically-shaped precursor structure for one or more cutter segment. In some examples, the blank construction may be cut along a plurality of straight paths substantially aligned with the longitudinal axis.

In some examples, the blank construction may be cut such that each cutter segment comprises a super-hard layer joined to a substrate comprising cemented carbide material.

In some examples, the axial (longitudinal) length of the super-hard layer may be greater than the length of a cutter segment and less than the combined length of two cutter segments. In some example, the super-hard layer may have an axial length of at most 6 (six) millimetres (mm), at most 8 (eight) millimetres (mm) or at most 10 (ten) millimetres (mm).

In some examples, the construction may have a diameter of at least 6 (six) millimetres (mm), at least 8 (eight) millimetres (mm) or at least 10 (ten) millimetres (mm). In some examples, the construction may have a diameter of at most 12 millimetres (mm) or at most 11 millimetres (mm).

In some examples, the method may include cutting at least one of the precursor structures to provide a precursor structure having reduced length.

In some examples, processing the precursor segment may include grinding or cutting it to form cutting edges, for example.

Viewed from a third aspect, there is provided a method of using a milling tool according to this disclosure, including milling a work-piece body by applying the milling tool to work-piece; in which the work-piece has a thickness of at least 9 millimetres (mm) or at least 12 mm.

In some examples, the work-piece body may comprise carbon fibre reinforced plastic (CRFP) material, metal or wood composite material.
In some examples, the method may include providing a milling tool according to this disclosure, for routing or edge trimming, and trimming the edge of a plate-like structure comprising a fibre-reinforced material, such as CFRP material, or composite wood-containing material. The milling tool may be configured as a compressive router or compressive edge trimming tool.

In some examples, the cutter segments may comprise PCBN material and the work-piece may comprise ferrous metal material, including alloy material, such as steel or super-alloy material. In some examples, the cutter segments may comprise PCD material and the work-piece may comprise CFRP, composite wood-containing material or non-ferrous metal materials, including non-ferrous alloy material.

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

Fig. 1A shows a schematic side view of an example end milling tool;
Fig. 1B shows a schematic end perspective view of the example end milling tool;
Fig. 1C shows a radial cross section through the example end milling tool;
Fig. 1D shows a schematic side view of an example cutter segment;
Fig. 2 shows a schematic view of part of an example blank construction remaining after example cutter elements have been cut out; and
Fig. 3 shows a schematic drawing of an example capsule for making an example blank construction.

With reference to Fig. 1A, Fig. 1B, Fig. 1C and Fig. 1D, an example end milling tool 10 has a longitudinal axis A about which the milling tool 10 will rotate in use in a direction R, comprising an elongate tool body 14 on which a plurality of cutter assemblies 16 are arranged azimuthally about the longitudinal axis A. Each cutter assembly 16 comprises a plurality of super-hard cutter segments 12 attached to the tool body 14 in an axial arrangement, each cutter segment 12 having a cutting edge 13. The tool body 14 and the cutter segments 12 are configured such that the cutting edges 13 define a mean cut diameter D of at least 6 (six) millimetres (mm) and a cut length L of at least 1.5 times the mean cut diameter D. In the particular example milling tool 10 illustrated, the cut length L is about 3.8 times the mean cut diameter D.
The milling tool 10 comprises a shaft 19 for attachment to a machine and a cutter region defined by the presence of cutter assemblies 16, each comprising three or four super-hard cutter segments 12 and extending an axial cut length L from a proximate end 17 of the milling tool 10. The cut diameter D is the diameter of a circle capable of circumscribing the cutting edges 13 on a lateral plane P that is perpendicular to the longitudinal axis A, as shown in Fig. 1C.

In the particular example milling tool 10 illustrated, there are six azimuthally arranged cutter assemblies 16, each lying on a helical path along part of part of the length of the tool body 14. The helical paths have both an axial (length-wise) and azimuthal (circumferential) component. The helical paths can be characterised by a helix angle H between a tangent to the helical path and the longitudinal axis A, when viewed from a side. The cutter segments 12 comprised in each of the cutter assemblies 16 are arranged generally end-to-end with each other along the helical paths, the ends of the cutter segments 12 slightly spaced apart. In the particular example illustrated, there are twenty one individual cutter segments 12 and alternate cutter assemblies 16 comprise three and four cutter segments 12, arranged such that the gaps between the cutter segments 12 of alternate assemblies 16 do not lie on the same lateral plane P.

Each cutter segment 12 comprises a respective cutting edge 13 at the intersection of a cutter face 15 (that will face a forward direction when rotating in use in direction R) and a land 11 (that will face a machined surface of the work-piece body in use). The cutter assemblies 16 may be viewed as being compound teeth for cutting a work-piece (not shown) and are distributed equidistantly about the longitudinal axis A. The cutter elements 12 comprised in each cutter assembly 16 are attached to the tool body 14 by braze material within helically arranged slots 18 provided on the tool body 14.

Each of the cutter segments 12 comprises a super-hard layer 22 bonded to a cemented carbide substrate 24. The land 11, cutter face 15 and the cutting edge 13 of each cutter segment 12 are provided on the super-hard layer 22, and each cutter segment 12 is attached to the tool body 14 by means of braze material between the substrate 24 and a slot 18 provided in the tool holder 14.

In general, the more cutter assemblies (teeth) comprised in the milling tool, the more rapidly it will likely be able to remove material.
An example method of making an example milling tool will be described.

An example blank construction may have a cylindrical external shape and may comprise a polycrystalline super-hard layer bonded to a generally cylindrical substrate core comprising cemented tungsten carbide material (in other words, the super-hard layer may be in the general form of a tube bonded to the substrate). At least part of the side of the blank construction may be coterminous with the super-hard layer. The super-hard layer may be joined to the substrate via at least one intermediate layer comprising super-hard grains dispersed within cemented carbide material. The intermediate layer may reduce internal stresses due to the difference in thermal expansion coefficients of the cemented carbide material of the substrate and the super-hard layer. Each intermediate layer may be about 0.2 to 0.3 millimetres (mm) thick. The blank construction may be configured such that the super-hard layer is spaced apart from at least one end of the blank construction by cemented carbide spacer member. The super-hard layer may extend all the way to the opposite end of the blank construction it may be spaced apart from each end by respective cemented carbide spacer members.

A core volume of the substrate may be removed by means of die sinking in combination with wire electro-discharge machining (WEDM) to provide a tube construction comprising the outer super-hard layer bonded to an inner cemented carbide tube. With reference to Fig. 2, a plurality of precursor structures for cutter segments may be cut from the tube construction along a plurality of helical paths, leaving tubular webbing as waste product (which may be used for another purpose). The webbing may comprise the cemented carbide spacer member 32 and a plurality of finger structures spaced apart azimuthally by gaps corresponding to the precursor structures for the cutter segments. In the particular example illustrated, eleven helical precursor structures have been cut from a tube construction.

An example method of making a blank construction will be described.

A pre-sinter assembly comprising an aggregation of super-hard grains, sinter promotion material for the super-hard grains and a substrate may be provided. The aggregation may contact the substrate and the sinter promotion material will be located
such that it will be capable of promoting the sintering of the aggregation. The shape
of the substrate and the aggregation will likely have the general shape of the desired
blank construction. The pre-sinter assembly may be encapsulated within a capsule for
an ultra-high pressure, high temperature furnace (which may also be referred to as an
ultra-high pressure press), which will be loaded into the furnace and subjected to a
sinter pressure and a sinter temperature at which the aggregation will sinter in the
presence of the sinter promotion material. The blank construction comprising the
sintered polycrystalline super-hard layer bonded to the substrate can then be removed
from the capsule.

With reference to Fig. 3, a particular example capsule 40 for insertion into a chamber
of a belt-type ultra-high pressure furnace (not shown) comprises a generally cylindrical
tube 43 closed at opposite ends by discs 41 and 49. The tube 43 and the discs 41 and
49 may comprise pyrophyllite or other refractory ceramic materials, for example. A
pre-sinter assembly comprising an aggregation 44 of super-hard grains arranged
circumferentially around a side 46 of a cylindrically shaped substrate core 47 may be
encapsulated within the closed tube 43. The substrate core 47 may consist of cobalt-
cemented tungsten carbide material and the aggregation 44 may comprise a plurality
of super-hard grains, such as diamond or cBN grains, and may substantially fill the
space between the substrate core 47 and an inner surface 45 of the tube 43. A spacer
structure 42 at an end of the substrate may extend from the substrate core 47 to the
inner side 45 of the tube. The spacer structure 42 may consist of cemented carbide
material a Young's modulus of about 400 gigapascals (GPa) and may likely have the
effect of reducing deformation of the aggregation 44 during the subsequent process of
sintering at an ultra-high pressure. The substrate core 47, aggregation 44 and tube 43
are substantially aligned with a longitudinal axis A, about which they have substantially
cylindrical symmetry.

In some example arrangements, the spacer structure may be an integral part of the
substrate (in other words, the spacer structure and the rest of the substrate may form
a unitary body). The spacer structure may extend laterally from a longitudinal core
structure of the substrate. In some example arrangements, the spacer structure may
comprise a ring-shaped or annular structure, or the spacer structure may be generally
configured as an end disc integrally formed with, attached to or abutting an end of the
substrate. In some example arrangements, the spacer structure may comprise a
slidable ring, into which a part of the substrate can be inserted. The slidable ring may be arranged at an end of the substrate or at an axial position remote from an end of the substrate, such as at or near the axial centre of the substrate. More than one ring may be used and arranged at different axial positions along the substrate, such as at opposite ends thereof. The aggregation of super-hard grains may be arranged in the pre-sinter assembly such that it abuts the slidable ring. The ring may comprise the same or a different material than that comprised in the substrate, and may become joined to the substrate during the manufacture of the blank construction. More than one spacer structure may be used, each arranged at a respective different longitudinal position along the substrate.

In some examples, the spacer structure may comprise hard-metal such as cemented tungsten carbide material; ceramic material such as alumina, silicon nitride, silicon carbide, zirconium oxide (zirconia) or tantalum oxide; nickel based super-alloy material such as Inconel™; super-hard material and or material containing super-hard grains, such as hard-metal or ceramic material containing grains of diamond or cubic boron nitride (cBN) dispersed therein. The substrate may comprise or consist of cobalt-cemented tungsten carbide material.

In general, the super-hard grains may comprise natural or synthetic diamond and or cubic boron nitride (cBN) and the sintered polycrystalline super-hard structure may comprise polycrystalline diamond (PCD) material, polycrystalline cubic boron nitride (PCBN) material, silicon carbide bonded diamond (SCD) material, and or cemented carbide material comprising super-hard grains.

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 milling), and cast into sheets using a plasticizer binder material such as PMMA, DBP and so forth. PCD material will result from sintering together the diamond by direct inter-growth.

In some examples, the aggregation may comprise a mixture of cubic boron nitride (cBN) grains and material for providing matrix material containing Ti, Al, W or Co, which may be cast into sheets using a plasticizer material. PCBN material will result from sintering the materials to provide cBN grains dispersed in a matrix comprising ceramic,
metallic, inter-metallic or super-alloy material, or a combination of these types of material.

The aggregation may comprise substantially loose super-hard grains or super-hard grains combined with a binder material for binding the grains together. The aggregation may comprise a plurality of filaments, foils or sheets comprising the super-hard grains. The method may include shredding or otherwise fragmenting sheets to provide the granules. The aggregation may comprise an extruded body comprising the super-hard grains.

In various examples, granules comprising the super-hard grains may be compacted against the substrate, or slurry comprising the super-hard grains may be injection molded to provide the aggregation. In one example version, the aggregation may be provided in the form of a plurality of diamond-containing foils. The foils may be cut from sheets comprising diamond grains held together by an organic binder and the sheets for intermediate layers may comprise diamond grains and tungsten carbide grains held together by an organic binder. The sheets may be made by a method such as extrusion or tape casting methods, in which slurry comprising diamond grains and a binder material is laid onto a surface and allowed to dry. Alternative methods for depositing diamond-bearing layers include spraying methods, such as thermal spraying.

In some examples, aggregations in the form of sheets comprising the diamond grains may be cut to size to fit around the core structure and a pre-sinter assembly may be constructed by wrapping the sheets around the core structure. In some example arrangements, sheets containing both diamond grains and tungsten carbide grains may be placed against the core structure and sheets free of tungsten carbide grains may be placed remote from the core structure, the carbide-containing sheets thus being disposed intermediate the core structure and the non-carbide containing sheets. Once sintered, these intermediate sheets may help reduce stress between the PCD structure and the core structure since certain of their properties will be intermediate those of PCD and cemented carbide material.

In some example variants of the method, the core structure 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.

Examples of sinter promotion material for diamond, for example, include certain metal materials including iron, cobalt, nickel and manganese and the sinter temperature may be sufficiently high for such metal material to be molten at the ultra-high pressure in the presence of carbon. Sinter promotion materials such as these are capable of promoting the direct inter-growth among the diamond grains comprised in the aggregation at the sinter pressure and sinter temperature. For example, cobalt present as cementing material in the cemented carbide substrate may be effective as a source of cobalt for sintering the aggregation. Additionally or alternatively, a source of cobalt or other sinter promotion material may be comprised in the aggregation as powder grains or microstructural depositions on the surfaces of the diamond grains. For example, the sinter promotion material may comprise cobalt comprised in the substrate, the ultra-high sinter pressure may be at least about 5.5 gigapascals (GPa) and the sinter temperature may be at least about 1,300 degrees Celsius; or the sinter pressure may be at least about 6.5 gigapascals (GPa) and the sinter temperature may be at least about 1,400 degrees Celsius.

In some examples, the aggregation may comprise a plurality of diamond grains having a mean size of 1 to 40 microns and a source of cobalt in particulate form. The capsule may be subjected to an ultra-high pressure of at least about 5.5 gigapascals (GPa) and heated to a temperature sufficiently high to melt the cobalt in the aggregation.

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 construction may have a diameter from about 10 to about 25 millimetres (mm).

Example milling tools may be for milling or routing a work-piece, particularly a work-piece comprising a hard or abrasive material such as metal, ceramic material,
composite material, wood, stone, concrete or masonry. For example, the milling tool may be a compression router for edge-trimming bodies comprising fibre-reinforced plastic materials, or a helical multi-flute router or a burr for the edge-finishing of bodies comprising composite materials.

Certain arrangements of rotary machine tools may have the aspect of enabling enhanced productivity, and certain arrangements may have the aspect that they exhibit more complex and sophisticated configuration of cutting edges, and or that they provide the tool designer with more flexibility in design of cutting edges so as to better meet the demands of the machining application. Certain disclosed example methods of making cutter elements may have the aspect of being easier or less costly to implement.

Milling tools according to this disclosure have the aspect of greater aspect ratio of cut length to cut diameter, allowing relatively thicker work-piece bodies to be milled using a milling tool with super-hard (compound) teeth. The disclosed method has the likely aspect that it enables such milling tools to be manufactured relatively easily and efficiently, owing to the modular nature of the cutter assemblies comprising two or more cutter segments. The method allows the cut diameter and the cut length to be provided as separate features as a consequence of assembling the cutter assemblies from individual cutter segments. Therefore, the configuration of the milling tool is substantially less limited by the constraints of manufacture of the super-hard cutters, which will likely permit greater flexibility in configuring the milling tools. Whilst example milling tools may require more steps and consequently more time to assemble, including more complex brazing steps, this may likely be compensated by reduced machining times arising from the use of super-hard cutter segments. In other words, more efficient machining, such as profiling of components, may potentially offset the likely increased time, cost and complexity of manufacturing the milling tool.

Non-limiting examples will be described below in more detail.

A cylindrical blank construction for making a PCD end mill or router can be manufactured as follows.
A pre-sinter assembly can be prepared, comprising a tubular aggregation of diamond grains surrounding a cylindrical cemented carbide substrate, encapsulated within a jacket comprising refractory material. The diamond grains may have a mean size of about 1 to 15 microns and the aggregation can be prepared by blending the diamond grains with powder comprising cobalt catalyst material for diamond. Plasticiser material can be introduced into the blend in order to make slurry that is sufficiently viscous for casting. The slurry can be cast into a sheet, which can be dried and shredded to provide a plurality of plate-like granules containing diamond grains.

A cylindrically shaped cobalt-cemented tungsten carbide rod can be provided, having a diameter of about 10.2 millimetres (mm). The rod, which will function as a substrate for a tubular PCD structure, can be placed concentrically within a cylindrical die for compacting powder, the inner diameter of the die being 11.5 millimetres (mm). A first cemented carbide spacer ring having thickness of about 1 millimetre (mm) can be placed around the rod between the rod and the die wall at the bottom of the die. 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 a tubular compaction tool that is 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 may be slightly larger (by about 0.05 millimetres (mm) for example) 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 may reduce the risk of non-uniform compaction and sintering 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 compaction tool can be applied to the second (top) spacer ring to compact the granules further and provide a dense green body aggregation, being a shaped and compacted aggregation still comprising the plasticiser, having a tubular shape 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 into a cup made of refractory metal, providing part of the jacket of the pre-sinter assembly. The pre-sinter 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 cups overlap each other, thus completely encasing the assembly to provide the pre-sinter assembly. The cups may be 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 pre-sinter assembly can be subject to an ultra-high sinter pressure of about 5.5 gigapascals (GPa) and a sinter 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 tube joined to a cemented carbide core. The pressure and temperature can then be reduced to ambient conditions and the capsule and metal cupping material removed by sand blasting and or acid treatment to provide a blank construction comprising a PCD tubular layer bonded to the rod, to opposite ends of which the carbide rings are joined. The diameter of the construction may be about 11.5 millimetres (mm), the axial length of the PCD layer may be about 13.5 millimetres (mm) and the PCD layer may be about 1.3 millimetres (mm) thick. More than one such blank construction may be provided in order to provide additional cutter segments.

The blank construction may be processed to provide a plurality of pre-cursor structures for a corresponding plurality of cutter segments. For example, a core cylindrical volume of the substrate can be removed by means of a combination of wire electro-discharge machining (WEDM) and die sinking, leaving a tubular construction comprising an outer PCD tube bonded to an inner substrate tube having substantially the desired thickness of the substrate of the cutter segments.

A series of helical cuts can be made through the tubular construction to cut out a plurality of elongate, helical pre-cursor structures for the cutter segments and leaving a webbing construction as waste. The pre-cursor structures will comprise respective
PCD layers bonded to respective substrates and have substantially the shape and dimensions of the desired cutter segments, according to a predetermined arrangement of the cutter segments for forming the cutter assemblies. The helical paths along which the construction is cut may have a helix angle of about 10 degrees, meaning that the path will lie at an angle of 10 degrees with respect to the longitudinal axis of the construction, when viewed laterally from the side. The helical pre-cursor structures may be at most about 12 millimetres (mm) in axial length and about 2 millimetres (mm) in width, with some being shorter so that when the pre-cursor structures are arranged en-to-end along a helical path, as in the cutter assemblies, the overall axial length of the cutter assemblies will be about 30 millimetres (mm). For example, at least some of the cutter assemblies may each comprise two cutter segments, each 12 millimetres (mm) in length, and one cutter of about 6 millimetres (mm) in length.

Each of the precursor structures can be further processed by cutting and grinding, for example, to provide respective cutting edges and sufficiently accurate final dimensions, within the tolerances of the desired milling tool, to provide the super-hard cutter segments.

A steel tool body for the milling tool can be provided, comprising a series of six azimuthally equidistant helical slots along the side, the slots configured for accommodating the substrates of the cutter segments. Three or four cutter segments can be brazed into each slot to provide six cutter assemblies, each comprising three or four cutter segments, the ends of which may be slightly spaced apart from each other. The tool body may have an overall length of about 50 to 60 millimetres (mm), including a shank and a cutting region, the latter characterised initially by the presence of the slots and ultimately by the presence of super-hard cutter segments.

The overall axial length of each cutter assembly may be about 30 millimetres (mm) along a helical path having a helix angle of about 10 degrees (with respect to the longitudinal axis of the milling tool). The diameter of the cutter body, the depth of the slot and the thickness of the cutter segments may be selected such that the cut diameter of the milling tool is about 10 millimetres (mm). Therefore, in this example, the cut length will be about 3 (three) times the cut diameter.
The cutter assemblies can be arranged such that alternating cutter assemblies have different numbers of cutter segments, arranged such that the gaps in azimuthally adjacent cutter assemblies are not aligned.

In other examples, the cutter segments can be joined to the tool body by other means, such as by means of adhesive material or mechanical means, such as interference fit or interlocking configuration.

The example milling tool can be used to perform a milling operation on the edge of a work-piece consisting of CFRP material and having a thickness of about 30 millimetres (mm).

A PCBN construction can be made analogously to the PCD construction described above, except that the slurry will comprise cBN grains instead of diamond grains and they may 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 grains may be at least about 0.5 micron and at most about 10 microns.

The table below lists dimensions of various example blank constructions comprising a super-hard tube joined to a substrate.
Certain terms and concepts as used herein are explained.

As used herein, a machine tool is a powered mechanical device that may be used to manufacture components by the selective removal of material from a work-piece, a process that may be referred to as machining. A rotary machine tool such as a drill bit or milling tool comprises at least one a cutter element and will spin (rotate) about a longitudinal axis of the tool in use. In a milling process, a spinning milling tool can be urged against a work-piece and advance in a direction that is substantially not aligned with its longitudinal rotation axis. For example, the milling tool may advance against the work-piece in a direction substantially perpendicular to the longitudinal rotation axis. Milling tools will comprise one or more cutter elements (which may be referred to as teeth) to remove material from the work-piece and examples of types of milling tools include end mills, slab mills, slot drills (which may be referred to as straight end mills) and face mills. Various terms as used herein in relation milling tools will be briefly explained below.

A cutter element of a milling tool will generally include a face, a land and a cutting edge lying at the intersection of the face and land. The face will comprise a rake face, against which chips will move when the machine tool is used to remove material from a body, the rake face directing the flow of newly formed chips (which are pieces of a work-piece removed in the machining process). A cutting edge is the edge of a rake face that is intended to cut a work-piece. The land is an outer surface of a cutter segment adjacent to the cutting edge, which will follow the cutting edge as the cutter segment rotates as in use. The land may be configured with a relief to reduce contact and friction between itself and the machined surface.
A flute is a recessed portion of a rotary machine tool that is capable of conveying chips away from a cutting edge as the tool rotates in use, the flute comprising the space between the back of one tooth and the face of the following tooth. A helical flute (also called a spiral flute) is arranged at least partially helically with respect to the longitudinal axis of rotation, defining a helix angle between a cutting edge and the longitudinal axis. Example rotary machine tools may have up to six or more cutting edges and flutes, the pitch being the azimuthal angular distance between like parts on adjacent cutter elements. Some milling tools may have relatively complex arrangements of flutes. For example, bi-directional flute arrangements comprise flutes along helical paths having opposite chirality, or handedness, in which the flutes may appear to cross each other. Milling tools having such flute arrangements may be suitable for removing burrs from a work-piece. In some examples, a milling tool may have first and second sets of flutes, the flutes in one set having opposite chirality (in other words, spiralling along opposite paths) to the flutes in the other set. The flutes in the first set may extend between a proximate and intermediate axial position and the flutes in the second set may extend between the intermediate and a distal axial position. The arrangement of the oppositely-spiralling sets of flutes may have the general appearance of a chevron arrangement on the tool body, and milling tools having such arrangements may be suitable for compression routing work-pieces comprising fibre-containing material, or other material than may be vulnerable to flaking, chipping or tearing during the milling process.

The cut length is the combined axial distance of all the cutter elements or cutter assemblies taken together. The cut length will limit the maximum depth to which a work-piece can be milled in a single pass. The overall length is the distance between opposite ends of the rotary machine tool, including a non-fluted shank for attaching the tool to a machine.

The mean cut diameter can be thought of as the mean diameter of a slot in a body capable of accommodating the entire cutting portion of a milling tool when it is inserted longitudinally into the slot, the cutting portion being defined by the presence of the cutter assemblies, taken together. In example arrangements in which the cutting edges are substantially equidistant from the longitudinal axis, the sides of the hole will be cylindrical and the mean cut diameter will be the diameter of the cylindrical hole. In
general, the greater the ratio of the cut length to the cut diameter, the greater will be the aspect ratio of the hole (in other words, the more elongate the hole).

As used herein, a super-hard material has a Vickers hardness of at least about 28 gigapascals (GPa). Diamond and cubic boron nitride (cBN) material are examples of super-hard materials. A super-hard cutter segment will comprise super-hard material, in which the cutting edge will be at least partly defined by super-hard material.

Polycrystalline diamond (PCD) material comprises an agglomeration of a plurality of diamond grains, a substantial portion of which are directly inter-grown with each other, the content of diamond being at least about 80 volume per cent of the material. Interstitial volumes between the diamond grains may be at least partly filled with filler material comprising sinter-promotion material for diamond (which may also be referred to as solvent / catalyst or simply catalyst material for diamond) or they may be substantially empty. A sinter-promotion material for synthetic diamond will be 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 catalyst materials for diamond are iron (Fe), nickel (Ni), cobalt (Co) and manganese (Mn), and certain alloys including these. Super-hard structures 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. PCD structures having at least a significant region from which catalyst material for diamond has been depleted, or in which catalyst material is in a form that is relatively less active as a catalyst, may be described as thermally stable PCD material.

PCBN material comprises grains of cubic boron nitride (cBN) dispersed within a hard matrix. For example, PCBN material may comprise at least about 30 volume per cent cBN grains dispersed in a binder matrix material comprising a Ti-containing compound, such as titanium carbonitride and or an Al-containing compound, such as aluminium nitride, and or compounds containing metal such as Co and or W. Some versions (or "grades") of PCBN material may comprise at least about 80 volume per cent or even at least about 85 volume per cent cBN grains.
In a cylindrical coordinate system, any point in three-dimensional space can be specified by its distance from a reference axis, its direction from the axis and its distance from a chosen reference plane perpendicular to the reference axis. The reference axis may be referred to as the longitudinal or cylindrical axis. A polar axis will lie in the reference plane, starting at the origin, being the point at which the longitudinal axis intersects the reference plane, and point in a reference direction. The distance from the longitudinal axis may be called the radial distance. The angular position of the point about the longitudinal axis may be referred to as the azimuthal position. Therefore, the position of a point may be described in terms of its axial position along the longitudinal axis, its azimuthal position about the longitudinal axis and its radial distance from the longitudinal axis. Cylindrical coordinates may be useful in connection with objects that have some rotational symmetry about the longitudinal axis, such as rotary machine tools.
A milling tool having a longitudinal axis about which the milling tool will rotate in use, comprising a tool body on which a plurality of cutter assemblies are arranged azimuthally, each cutter assembly comprising a plurality of super-hard cutter segments attached to the tool body in an axial arrangement, each cutter segment having a cutting edge; in which the tool body and the cutter segments are configured such that the cutting edges define a mean cut diameter of at least 6 (six) millimetres (mm) and a cut length of at least 1.5 times the mean cut diameter.

2. A milling tool as claimed in claim 1, in which the super-hard cutter segments comprise polycrystalline diamond (PCD) material or polycrystalline cubic boron nitride (PCBN) material.

3. A milling tool as claimed in claim 1 or claim 2, in which each cutter assembly is arranged such that the cutting edges may lie on a straight path that is substantially parallel to the longitudinal axis.

4. A milling tool as claimed in any of the preceding claims, in which the cut length is at least 2 times (twice) times the mean cut diameter.

5. A milling tool as claimed in any of the preceding claims, in which each cutter assembly comprises at least 2 (two) cutter segments.

6. A milling tool as claimed in any of the preceding claims, comprising a first set of cutter assemblies and a second set of cutter assemblies, the cutter segments comprised in the first and second cutter assemblies arranged such that the respective cutter assemblies have opposite chirality.

7. A milling tool as claimed in claim 6, in which the first and second sets of cutter assemblies lie on intersecting helical paths.

8. A milling tool as claimed in claim 6, in which the first set of cutter assemblies is arranged on a first cutter region of the tool body adjacent a proximate end, and
the second set is arranged on a second cutter region remote from the proximate end and adjacent the first cutter region.

9. A milling tool as claimed in claim 8, in which the cutter assemblies are arranged in relation to the direction of rotation of the milling tool in use such that the milling tool will be capable of putting an edge of a work-piece into compression while the spinning milling tool is being urged against it.

10. A method of making a milling tool according to this disclosure, the method including providing an elongate tool body having a longitudinal axis, and a plurality of super-hard cutter segments having respective cutting edges and configured such that they can be arranged to provide the cutter assemblies; and attaching the cutter segments to the tool body, the cutter segments being arranged axially along the tool body to provide the respective cutter assemblies; in which the tool body and the cutter segments are configured such that the cutting edges define a mean cut diameter of at least 6 (six) millimetres (mm) and a cut length of at least 1.5 times the mean cut diameter.

11. A method as claimed in claim 10, in which the tool body is provided with recesses for accommodating the cutter segments.

12. A method as claimed in claim 10 or claim 11, in which each cutter segment comprises a super-hard layer joined to a substrate comprising cemented carbide material.

13. A method as claimed in any of claims 10 to 12, in which each cutter assembly comprises at least two cutter segments.

14. A method as claimed in any of claims 10 to 13, in which the cut is at least two times (twice) the cut diameter.

15. A method as claimed in any of claims 10 to 14, including providing a super-hard construction comprising a super-hard layer bonded to a boundary of a substrate comprising hard-metal, the construction having opposite ends connected by an azimuthally arcuate side, at least partly coterminous with the
super-hard layer; cutting the construction axially to provide a plurality of precursor structures for the cutter segments and processing the precursor structures to provide the plurality of cutter segments.

16. A method as claimed in claim 15, in which the arcuate side is cylindrical in shape.

17. A method as claimed in claim 15 or 16, in which the super-hard layer is in the form of a tube surrounding a substantially cylindrical substrate core.

18. A method as claimed in any of claims 15 to 17, including cutting the construction along a helical path about the longitudinal axis to provide at least one helically-shaped precursor structure for one or more cutter segment.

19. A method as claimed in any of claims 15 to 18, including cutting the construction along a plurality of helical paths extending axially and circumferentially along the arcuate side to provide the plurality of helical precursor structures.

20. A method as claimed in any of claims 15 to 19, in which the axial length of the super-hard layer is greater than the length of a cutter segment and less than the combined lengths of two cutter segments.

21. A method as claimed in any of claims 15 to 20, in which the construction has a diameter of at least 6 (six) millimetres (mm).

22. A method as claimed in any of claims 15 to 21, in which the super-hard layer has an axial length of at most 6 (six) millimetres (mm).

23. A method of using a milling tool as claimed in any of claims 1 to 9, the method including milling a work-piece body by applying the milling tool to work-piece; in which the work-piece has a thickness of at least 9 millimetres (mm).

24. A method as claimed in claim 23, in which the work-piece body comprises carbon fibre reinforced plastic (CRFP) material, metal or wood composite material.
25. A method as claimed in claim 23 or claim 24, in which the milling tool is configured for routing, and trimming the edge of a plate-like structure comprising a fibre-reinforced material.

26. A method as claimed in any of claims 23 to 25, in which the cutter segments comprise PCBN material and the work-piece comprises ferrous metal material.

27. A method as claimed in any of claims 23 to 26, in which the cutter segments comprise PCD material and the work-piece comprises CFRP, composite wood-containing material or non-ferrous metal material.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B23C5/10

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)

B23C B23P B22F

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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**Date of the actual completion of the international search**

27 October 2014

**Date of mailing of the international search report**

12/11/2014

**Name and mailing address of the ISA**

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Authorized officer

Barrow, Jeffrey
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