



(11) **EP 2 567 784 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
31.07.2019 Bulletin 2019/31

(51) Int Cl.:
B24D 3/14 (2006.01)

(21) Application number: **11180639.4**

(22) Date of filing: **08.09.2011**

(54) **Bonded abrasive article**

Gebundener Schleifartikel

Article abrasif fixé

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME

(43) Date of publication of application:
13.03.2013 Bulletin 2013/11

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US-A1- 2010 151 196

EP 2 567 784 B1

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Description

[0001] The present invention relates to bonded abrasive articles, particularly those which are useful in high performance grinding.

[0002] Abrasive machining using bonded abrasive articles (such as grinding wheels) continues to develop its capabilities. This development has created an increasing demand for high-performance grinding wheels: wheels which can remove material faster at exacting tight tolerances, but without causing damage at the workpiece, thus able to provide reductions in grinding cycle time and lower grinding costs per part.

[0003] Bonded abrasive articles have abrasive particles bonded together by a bonding medium. The main types of bonding systems used to make bonded abrasive articles are: resinoid, vitrified, and metal. Resinoid bonded abrasives utilize an organic binder system (e.g., phenolic binder systems) to bond the abrasive particles together to form the shaped mass. Another major type are bonded abrasive articles (for example vitrified bonded wheels) in which a vitreous binder system is used to bond the abrasive particles together. These bonds are usually vitrified at temperatures between 700°C to 1500°C. Metal bonded abrasive articles typically utilize sintered or plated metal to bond the abrasive particles. Vitrified bonded abrasive articles are different from resinoid bonded abrasive articles in that they use a vitreous phase to bond the abrasive grain and thus are processed at substantially higher temperatures. Vitrified bonded abrasive articles can withstand higher temperatures in use and are generally more rigid and brittle than resinoid bonded wheels.

[0004] Bonded abrasives are three dimensional in structure and typically include a shaped mass of abrasive particles, held together by the binder. Such shaped mass can be, for example, in the form of a wheel, such as a grinding wheel. Ideal bonded abrasive articles have a long life time and are able to abrade the workpiece with constant cut over time. However, when the abrasive particles are worn and dulled, these abrasive particles are expelled from the bonded abrasive to expose new, fresh cutting abrasive particles. In the ideal situation, the bonded abrasive article is self-sharpening. However, in reality, particularly, when the forces get high enough, the bonded abrasive articles can break down, breaking and ejecting grit particles and the grinding power drawn decreases beyond the starting value of the grinding application as the bonded abrasive article wears away rapidly and loses its preferred shape. Bonded abrasive articles therefore typically show cyclical grinding curves (grinding power consumption as a function of grinding time). At the end point of a grinding cycle dressing of the bonded abrasive article (such as a grinding wheel) has to be set up in order to avoid defects at the workpiece to be abraded and in order to provide for constant abrading performance of the bonded abrasive article. Dressing is typically performed using a dressing tool such as a diamond dressing tool. Frequent dressing cycles are undesirable since the production process has to be interrupted frequently which will add on costs, besides reducing service life of the wheel. What is desired in the industry is a bonded abrasive article requiring a minimum of dressing cycles resulting in a long total service life of the wheel. Such an article typically draws a minimum of power when operating.

[0005] Vitrified bonded grinding wheels incorporating irregularly shaped (for example, crushed) abrasive particles are known to be useful for abrading workpieces such as hardened and unhardened metal components. However, the dressing cycles of these abrasives articles can be more frequent than desired, i.e., resharpener has to be set up more frequently to avoid dulling of the grains. Sometimes constant grinding performance in terms of workpiece quality and/or long dressing cycles cannot be provided, particularly under severe grinding conditions, e.g., high feed rates. In particular, in case of a grinding cycle not having a phase of substantially constant grinding performance (for example in terms of material removal rate) over a period of time it can be difficult to achieve constant grinding results of the workpiece to be abraded.

[0006] What is desired in the industry is a bonded abrasive article, for example, a grinding wheel, that has an improved service life and can provide constant grinding results (particularly in terms of surface quality of the workpiece) over a long period of time, particularly under severe grinding conditions.

[0007] Surprisingly, it has been found that shaped abrasive particles in combination with a vitrified bond can provide abrasive articles which can solve the aforementioned problems. In particular, such articles have been found to be particularly effective in high performance grinding applications.

[0008] The present invention relates to a bonded abrasive article comprising shaped abrasive particles and a bonding medium comprising a vitreous bond, said shaped abrasive particles each comprising a first side and a second side separated by a thickness t , wherein said first side is a first face having a perimeter of a first geometric shape, wherein the thickness t is smaller than the length of the shortest side-related dimension of the particle, wherein the second side either comprises a vertex or a ridge line or a second face having a perimeter of a second geometric shape which may be the same or different to the first geometric shape, wherein said first and second geometric shapes are independently selected from regular and irregular polygonal shapes, wherein the length of the shortest side related dimension of the particle is the length of the shortest facial dimension of the first face (if the particle has no second face) or is the length of the shortest facial dimension of the larger face of the particle (if the particle has a second face), wherein said vitreous bond comprises, based on the total weight of the vitreous bond, 25 to 90 % by weight of SiO_2 .

[0009] Typically, the ratio of the length of the shortest side related dimension to the thickness of said particle is at least 1:1.

[0010] The present invention also relates to the use of the bonded abrasive articles in high performance grinding applications and to a method for abrading a workpiece.

FIG. 1 illustrates a graph of the grinding power consumption as a function of the grinding time for Type I Wheels of Examples 1A-1, 1A-2, 2A-1 and 3A-1 and Comparative Examples Ref. 1A-2, Ref. 2A-1, and Ref. 3A-2 using the conditions of Test Series (I).

FIG. 2 illustrates a graph of the grinding power consumption as a function of the grinding time for the Type II Wheels of Examples 1B-1, 1B-2, 2B-1 and 3B-1 using the conditions of Test Series (I).

FIG. 3 illustrates a graph of the grinding power consumption as a function of the grinding time for Type I Wheels of Examples 1A-1, 1A-2, 2A-1 and 3A-1 and Comparative Examples Ref. 1A-2, Ref. 2A-1, and Ref. 3A-1 using the conditions of Test Series (II).

FIG. 4 illustrates a graph of the grinding power consumption as a function of the grinding time for Type II Wheels of Examples 1B-1, 1B-2, 2B-1 and 3B-1 using the conditions of Test Series (II).

FIG. 5 shows a graph illustrating the surface roughness Ra obtained for Type I Wheels of Examples 1A-1, 2A-1, 3A-1, 1A-2 and Comparative Examples Ref. 1A-1, Ref. 2A-1, Ref. A-1 and Ref. 3A-2.

FIG. 6A is a schematic top view of exemplary shaped abrasive particle 320.

FIG. 6B is a schematic side view of exemplary shaped abrasive particle 320.

FIG. 6C is a cross-sectional top view of plane 3-3 in FIG. 6B.

FIG. 6D is an enlarged view of side edge 327a in FIG. 6C.

[0011] While the above-identified drawing figures set forth several embodiments of the present disclosure, other embodiments are also contemplated, as noted in the discussion. The figures may not be drawn to scale. Like reference numbers may have been used throughout the figures to denote like parts.

[0012] As used herein, forms of the words "comprise", "have", and "include" are legally equivalent and open-ended. Therefore, additional non-recited elements, functions, steps or limitations may be present in addition to the recited elements, functions, steps, or limitations.

[0013] As used herein, the term "abrasive dispersion" means a precursor (in typical cases an alpha alumina precursor) that can be converted into an abrasive material (for example, alpha alumina) that is introduced into a mold cavity. The composition is referred to as an abrasive dispersion until sufficient volatile components are removed to bring about solidification of the abrasive dispersion.

[0014] As used herein, the term "precursor shaped abrasive particle" means the unsintered particle produced by removing a sufficient amount of the volatile component from the abrasive dispersion, when it is in the mold cavity, to form a solidified body that can be removed from the mold cavity and substantially retain its molded shape in subsequent processing operations.

[0015] As used herein, the term "shaped abrasive particle", means an abrasive particle with at least a portion of the abrasive particle having a predetermined shape that is replicated from a mold cavity used to form the shaped precursor abrasive particle. Except in the case of abrasive shards (e.g. as described in US Patent Application Publication Nos. 2009/0169816 and 2009/0165394), the shaped abrasive particle will generally have a predetermined geometric shape that substantially replicates the mold cavity that was used to form the shaped abrasive particle. Shaped abrasive particle as used herein excludes abrasive particles obtained by a mechanical crushing operation.

[0016] As used herein, the term "nominal" means: of, being, or relating to a designated or theoretical size and/or shape that may vary from the actual.

[0017] The present invention relates to a bonded abrasive article comprising specific shaped abrasive particles (which can be typically characterized as thin bodies) and a bonding medium comprising a vitreous bond. The present invention also relates to the use of an article according to the present invention in grinding applications, in particular in high performance grinding applications and to the use of an article according to the present invention for abrading a workpiece material particularly a workpiece material selected from steels, non-ferrous metals, and alloys. In addition, the present invention relates to a method for abrading a workpiece, the method comprising frictionally contacting at least a portion

of an abrasive article according to the invention with a surface of a workpiece; and moving at least one of the workpiece or the abrasive article to abrade at least a portion of the surface of the workpiece.

[0018] In accordance with the present invention, the bonded abrasive article comprises shaped abrasive particles. Three basic technologies that have been employed to produce abrasive grains having a specified shape are (1) fusion, (2) sintering, and (3) chemical ceramic. In the present invention, it is preferred to use shaped abrasive particles produced by chemical ceramic technology, i.e., ceramic shaped abrasive particles.

[0019] In one embodiment, the ceramic shaped abrasive particles comprise alpha alumina, i.e. the particles are alpha alumina based ceramic shaped particles.

[0020] In one embodiment, the ceramic shaped abrasive particles comprise sol-gel derived alumina based abrasive particles. Both seeded and non-seeded sol-gel derived alumina based abrasive particles can be suitably used in accordance with the present invention. However, in some instances, it may be preferred to use non-seeded sol-gel derived alumina based abrasive particles.

[0021] The materials that can be made into shaped abrasive particles of the invention include any suitable hard or superhard material known to be suitable for use as an abrasive particle. Accordingly, in one embodiment, the shaped abrasive particles comprise a hard abrasive material. In another embodiment, the shaped abrasive particles comprise a superhard abrasive material.

[0022] Specific examples of suitable abrasive materials include known ceramic materials, carbides, nitrides and other hard and superhard materials such as aluminum oxide (for example alpha alumina) materials (including fused, heat treated, ceramic and sintered aluminum oxide materials), silicon carbide, titanium diboride, titanium nitride, boron carbide, tungsten carbide, titanium carbide, diamond, cubic boron nitride (CBN), garnet, alumina-zirconia, sol-gel derived abrasive particles, cerium oxide, zirconium oxide, titanium oxide or a combination thereof.

[0023] The most useful of the above are typically based on alumina, and in the specific descriptions that follow the invention may be illustrated with specific reference to alumina. It is to be understood however that the invention is not limited to alumina but is capable of being adapted for use with a plurality of different hard and superhard materials.

[0024] Hard abrasive materials can be typically characterized as having a Knoop Hardness of 3500 kgf/mm² or less (typically, about 1500 to about 3000 kgf/mm²).

[0025] Superhard abrasive materials can be characterized as having a Knoop Hardness of more than 3500 kgf/mm² (typically, about 4000 to about 9000 kgf/mm²)

Most oxide ceramics have a Knoop hardness in the range of 1000 to 1500 kgf/mm² (10 - 15 GPa), and many carbides are over 2000 kgf/mm² (20 GPa). The method is specified in ASTM C849, C1326 & E384.

[0026] It is also within the scope of the present invention to use abrasive particles that have a surface coating for example of inorganic particles thereon. Surface coatings on the shaped abrasive particles may be used to improve the adhesion between the shaped abrasive particles and a binder material in abrasive articles, or can be used to aid in electrostatic deposition of the shaped abrasive particles. In one embodiment, surface coatings as described in U.S. Patent No. 5,352,254 (Celikkaya) in an amount of 0.1 to 2 percent surface coating to shaped abrasive particle weight may be used. Such surface coatings are described in U.S. Patent Nos. 5,213,591 (Celikkaya et al.); 5,011,508 (Wald et al.); 1,910,444 (Nicholson); 3,041,156 (Rowse et al.); 5,009,675 (Kunz et al.); 5,085,671 (Martin et al.); 4,997,461 (Markhoff-Matheny et al.); and 5,042,991 (Kunz et al.). Additionally, the surface coating may prevent the shaped abrasive particle from capping. Capping is the term to describe the phenomenon where metal particles from the workpiece being abraded become welded to the tops of the shaped abrasive particles. Surface coatings to perform the above functions are known to those skilled in the art.

[0027] The shaped abrasive particles of the present invention have substantially precisely formed three-dimensional shapes. Typically, the shaped abrasive particle generally have a predetermined geometric shape, for example one that substantially replicates the mold cavity that was used to form the shaped abrasive particle.

[0028] Typically, the shaped abrasive particles can be characterized as thin bodies. As used herein the term thin bodies is used in order to distinguish from elongated or filamentary particles (such as rods), wherein one particle dimension (length, longest particle dimension) is substantially greater than each of the other two particle dimensions (width and thickness) as opposed to particle shapes useful in the present invention wherein the three particle dimensions (length, width and thickness as defined herein) are either of the same order of magnitude or two particle dimensions (length and width) are substantially greater than the remaining particle dimension (thickness). Conventional filamentary abrasive particles can be characterized by an aspect ratio, that is the ratio of the length (longest particle dimension) to the greatest cross-sectional dimension (the greatest cross-sectional dimension perpendicular to the length) of from about 1:1 to about 50:1, preferably of from about 2:1 to about 50:1 and more typically greater than about 5:1 to about 25:1. Furthermore, such conventional filamentary abrasive particles are characterized by a cross-sectional shape (the shape of a cross section taken perpendicular to the length or longest dimension of the particle) which does not vary along the length.

[0029] In contrast hereto, shaped abrasive particles according to the present invention can be typically characterized by a cross-sectional shape that varies along the length of the particle. The length is the longest particle dimension, the width is the maximum particle dimension perpendicular to the length. The thickness as referred to herein is also typically

perpendicular to length and width.

[0030] The abrasive particles generally each comprise a first side and a second side separated by a thickness t . The first side is

a first face (in typical cases a planar face) having a perimeter of a first geometric shape.

[0031] The thickness t is smaller than the length of the shortest side-related dimension of the particle.

[0032] The second side either comprises a vertex separated from the first side by thickness t , or the second side comprises a ridge line separated from the first side by thickness t , or the second side comprises a second face separated from the first side by thickness t .

[0033] For example, the second side may comprise a vertex and at least one sidewall connecting the vertex and the perimeter of the first face (illustrative examples include pyramidal shaped particles, for example tetrahedral-shaped particles).

[0034] Alternatively, the second side may comprise a ridge line and at least one sidewall connecting the ridge line and the perimeter of the first face (illustrative examples include roof-shaped particles).

[0035] Alternatively, the second side may comprise a second face and at least one sidewall (which may be a sloping sidewall) connecting the second face and the first face (illustrative examples include triangular prisms or truncated pyramids).

[0036] Blends of different shapes of the abrasive particles in accordance with the present invention can be used in the bonded abrasive articles of the present invention. A blend of shaped abrasive particles can comprise a first plurality of shaped abrasive particles in accordance with the present invention and a second plurality of shaped abrasive particles in accordance with the present invention wherein the particles of the first plurality are different from the second plurality. Differences can for example be selected based on the shape or grade or chemical composition of the abrasive particle.

[0037] The thickness t may be the same (for example in embodiments wherein the first and second sides comprise parallel planar faces) or vary over the planar configuration of the particle (for example in embodiments wherein one or both of the first and second sides comprise non-planar faces or in embodiments wherein the second side comprises a vertex or a ridge line as discussed in more detail later herein).

[0038] The thickness is smaller than the length of the shortest side-related dimension (the shortest dimension of the first side and the second side of the particle; the length of the shortest side-related dimension of the particle may also be referred to herein as the length of the shortest facial dimension of the particle).

[0039] In most cases, the ratio of the length of the shortest side-related dimension of the shaped abrasive particle to the thickness of the shaped abrasive particle is at least 1:1 but can range from 1:1 to 10:1, more preferably from 2:1 to 8:1 and most preferably from 3:1 to 6:1. This ratio is also referred to herein as primary aspect ratio.

[0040] As used herein, the term "thickness", when applied to a particle having a thickness that varies over its planar configuration, shall mean the maximum thickness. If the particle is of substantially uniform thickness, the values of minimum, maximum, mean, and median thickness shall be substantially equal. For example, in the case of a triangle, if the thickness is equivalent to "a", the length of the shortest side of the triangle is preferably at least "2a". In the case of a particle in which two or more of the shortest facial dimensions are of equal length, the foregoing relationship continues to hold. In most cases, the shaped abrasive particles are polygons having at least three sides, the length of each side being greater than the thickness of the particle. In the special situation of a circle, ellipse, or a polygon having very short sides, the diameter of the circle, minimum diameter of the ellipse, or the diameter of the circle that can be circumscribed about the very short-sided polygon is considered to be the shortest facial dimension of the particle.

[0041] For further illustration, in case of a tetrahedral shaped abrasive particle, the length would typically correspond to the side length of one triangle side, the width would be the dimension between the tip of one triangle side and perpendicular to the opposite side edge and the thickness would correspond to what is normally referred to as "height of a tetrahedron", that is, the dimension between the vertex and perpendicular to the base (or first side).

[0042] If an abrasive particle is prepared in a mold cavity having a pyramidal, conical, frusto-pyramidal, frusto-conical, truncated spherical, or a truncated spheroidal shape, the thickness is determined as follows: (1) in the case of a pyramid or cone, the thickness is the length of a line perpendicular to the base of the particle and running to the apex of the pyramid or cone; (2) in the case of a frusto-pyramid or frusto-cone, the thickness is the length of a line perpendicular to the center of the larger base of the frusto-pyramid or of the frusto-cone and running to the smaller base of the frusto-pyramid or of the frusto-cone; (3) in the case of a truncated sphere or truncated spheroid, the thickness is the length of a line perpendicular to the center of the base of the truncated sphere or truncated spheroid and running to the curved boundary of the truncated sphere or truncated spheroid.

[0043] The length of the shortest side-related dimension of the particle is the length of the shortest facial dimension of the base of the particle (if the particle has only one base, typically the first face) or the length of the shortest facial dimension of the larger base of the particle (if the particle has two bases, for example in cases where the second side comprises a second face).

[0044] The thickness of the particles is not particularly limited. For example in typical cases, the thickness can be about 5 micrometers or more, or about 10 micrometers or more, or about 25 micrometers or more, or about 30 micrometers

or more, or even about 200 micrometers or more. The upper limit of the thickness can be selected to be about 4 mm or less, or about 3 mm or less for large particles, or about 1600 micrometers or less, or about 1200 micrometers or less, or about 100 micrometers or less, or about 500 micrometers or less or about 300 micrometers or less or even about 200 micrometers or less.

[0045] As used herein in referring to shaped abrasive particles, the term "length" refers to the maximum dimension of a shaped abrasive particle. In some cases the maximum dimension may be along a longitudinal axis of the particle, although this is not a necessary requirement. "Width" refers to the maximum dimension of the shaped abrasive particle that is perpendicular to the length. "Thickness" refers to the dimension of the shaped abrasive particle that is perpendicular to the length and width.

[0046] The shaped abrasive particles are typically selected to have a length in a range of from 0.001 mm to 26 mm, more typically 0.1 mm to 10 mm, and more typically 0.5 mm to 5 mm, although other lengths may also be used. In some embodiments, the length may be expressed as a fraction of the thickness of the bonded abrasive article in which it is contained. For example, the shaped abrasive particle may have a length greater than half the thickness of the bonded abrasive wheel. In some embodiments, the length may be greater than the thickness of the bonded abrasive wheel.

[0047] The shaped abrasive particles are typically selected to have a width in a range of from 0.001 mm to 26 mm, more typically 0.1 mm to 10 mm, and more typically 0.5 mm to 5 mm, although other dimensions may also be used.

[0048] The dimensions of the shaped abrasive particle (such as length, width and thickness) can be determined using methods known in the art, for example, by using conventional measuring tools such as rulers, vernier callipers, micrometers, or microscopy measurement techniques and typically calculating the average of a suitable number of measurements.

[0049] For example, a measuring microscope such as a Nikon MM-40 obtained from Nikon Americas Inc. in Melville, NY according to the following test method can be used: One or more shaped abrasive particles are supported on a glass slide preferably by its largest substantially planar surface (if it has one) in contact with the glass slide (dished or concave surface up if the particle has one.) The glass slide is then placed on the Nikon MM-40 microscope stage. The stage has the ability to move in the X and Y direction and it is also equipped with counters for the X-Y distance travelled. The crosshair is aligned with one of the exterior vertices of the shaped abrasive particle. For example, a thin triangular particle would use one of the three vertices; a rectangular base pyramid would use one of the four rectangular base vertices of the pyramid. The X and Y counters are then reset to zero. The crosshair is then moved clockwise to the next exterior vertex of the geometry being measured and the X and Y readings are recorded. The remaining exterior vertices moving in a clockwise direction are then sequentially measured. The X and Y coordinates of each exterior vertex can then be placed into a spreadsheet and the maximum dimension between any two of the vertices calculated using Pythagoras' theorem.

[0050] For a triangle the length is maximum distance between any two adjacent vertices of the three vertices. For a rectangle, the length is the maximum dimension between adjacent vertices. For an elongated parallelogram, the length is the maximum dimension between adjacent vertices. For a kite or a rhombus, the length is the maximum dimension between opposing vertices. The maximum dimension to determine length for alternative geometries can be determined by those of skill in the art when looking at the geometry in the microscope. The width can then be determined perpendicular to the length by using the coordinates of selected vertices or by rotating the stage or slide such that the length dimension is parallel to the X-axis. For a triangle the width is the maximum distance between the side with the longest adjacent vertices and the opposing vertex. For a rectangle, the width is the largest dimension between the two pair of shorter opposing vertices. For an elongated parallelogram, the width is the maximum dimension between the side with the longest adjacent vertices and the opposing side. For a kite or a rhombus, the width is the shorter dimension between opposing vertices. The maximum dimension to determine width for alternative geometries can be determined by those of skill in the art when looking at the geometry in the microscope.

[0051] The Nikon MM-40 microscope is also equipped with a Z-axis scale with a counter. To measure thickness, t , (height from glass slide) the viewfield is first focused on the upper surface of the glass slide using the 100x objective for maximum accuracy. The Z counter is then reset to zero. The viewfield is then moved to the highest possible point of the shaped abrasive particle that can be observed (a lower magnification may be needed to find the highest point) and the microscope refocused at that the highest point at the 100x magnification. The particle's thickness is determined by the Z reading after refocusing.

[0052] At least 20 shaped abrasive particles are measured for the dimension of interest (individual length, individual width, individual thickness). The averages of the dimension of interest (individual lengths, widths, thickness dimensions) are determined to define the dimension (length, width, thickness) for the measured shaped abrasive particles respectively.

[0053] For the purposes of this measurement, the thickness of a particle having an opening is measured at the site of the actual maximum thickness of the particle (i.e. typically not within the opening). The shortest side related dimension, the width and the length of a particle having an opening are typically measured without subtracting the length of overlap of the opening with any one of these dimensions (if any). For example, the width and length of an equilateral, prismatic particle having an opening extending between the first and the second side of uniform thickness t can be measured

based on the perimeter of the first face (or the second face) without taking into account the opening.

[0054] The shaped abrasive particles can have various volumetric aspect ratios. The volumetric aspect ratio is defined as the ratio of the maximum cross sectional area passing through the centroid of a volume divided by the minimum cross sectional area passing through the centroid. The volumetric aspect ratio can be determined using methods known in the art, for example by using the actual maximum and minimum cross sectional areas of the particle, and/or exterior dimensions determined by microscopy measurement techniques as previously described and calculating the average of a suitable number (for example 20 or more) of individual particle determinations. For an equilateral triangular shaped abrasive particle, the thickness and side length can be measured by microscopic techniques discussed above and the volumetric aspect ratio determined.

[0055] For some shapes, the maximum or minimum cross sectional area may be a plane tipped, angled, or tilted with respect to the external geometry of the shape. For example, a sphere would have a volumetric aspect ratio of 1.000 while a cube will have a volumetric aspect ratio of 1.414. A shaped abrasive particle in the form of an equilateral triangle having each side equal to length A and a uniform thickness equal to A will have a volumetric aspect ratio of 1.54, and if the uniform thickness is reduced to 0.25 A, the volumetric aspect ratio is increased to 2.64. It is believed that shaped abrasive particles having a larger volumetric aspect ratio have enhanced cutting performance.

[0056] In various embodiments of the invention, the volumetric aspect ratio for the shaped abrasive particles can be greater than about 1.15, or greater than about 1.50, or greater than about 2.0, or between about 1.15 to about 10.0, or between about 1.20 to about 5.0, or between about 1.30 to about 3.0.

[0057] The abrasive particles are preferably in the shape of thin three-dimensional bodies having various three-dimensional shapes. The first side generally is a first face having a perimeter of a first geometric shape.

[0058] The first and second geometric shapes are independently selected from regular and irregular polygonal shapes.

[0059] For example, the first geometric shape can be selected from geometric shapes having at least one vertex, more typically two or more, preferably three or more, most preferably three or four vertices.

[0060] Suitable examples for geometric shapes having at least one vertex include polygons (including equilateral, equiangular, star-shaped, regular and irregular polygons).

[0061] Specific examples for suitable polygonal geometric shapes include triangular shapes and quadrilateral shapes (for example a square, a rectangle, a rhombus, a rhomboid, a trapezoid, a kite, or a superellipse).

[0062] The vertices of suitable quadrilateral shapes can be further classified as a pair of opposing major vertices that are intersected by a longitudinal axis and a pair of opposing minor vertices located on opposite sides of the longitudinal axis. Shaped abrasive particles having a first side having this type of quadrilateral shape can be characterized by an aspect ratio of a maximum length along a longitudinal axis divided by the a maximum width transverse to the longitudinal axis of 1.3 or greater, preferably 1.7 to about 5. This aspect ratio is also referred to herein as secondary aspect ratio.

[0063] A rhombus is a quadrilateral having four edges of equal length and wherein opposing vertices have included angles of equal degrees as seen in FIGS. 1 and 3 of WO 2011/068714. A rhomboid is a parallelogram wherein the two intersecting edges on one side of the longitudinal axis are of unequal lengths and a vertex between these edges has an oblique included angle as seen in FIG. 4 of WO 2011/068714. A kite, as seen in FIG. 5 of WO 2011/068714, is a quadrilateral wherein the two opposing edges above a transverse axis are of equal length and the two opposing edges below the transverse axis are of equal length, but have a different length than the edges above the transverse axis. If one took a rhombus and moved one of the opposing major vertices either closer to or further away from the transverse axis a kite is formed.

[0064] A superellipse is a geometric figure defined in the Cartesian coordinate system as the set of all points (x, y) defined by Lamé's curve having the formula

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

where n, a and b are positive numbers. When n is between 0 and 1, the superellipse looks like a four-armed star with concave edges (without the scallops) as shown in FIG. 2 of WO 2011/068714. When n equals 1, a rhombus a=b or a kite a<>b is formed. When n is between 1 and 2 the edges become convex.

[0065] In some embodiments it is particularly preferred that the first geometric shape is selected from triangular shapes, such as an isosceles triangular shape or, more preferably, an equilateral triangular shape.

[0066] In other embodiments, the first geometric shape is selected from quadrilateral shapes, preferably from the group of a square, a rectangle, a rhombus, a rhomboid, a trapezoid, a kite, or a superellipse, more preferably from the group of a rectangle, a rhombus, a rhomboid, a kite or a superellipse.

[0067] For the purposes of this invention geometric shapes are also intended to include regular or irregular polygons

or stars wherein one or more edges (parts of the perimeter of the face) can be arcuate (either of towards the inside or towards the outside, with the first alternative being preferred). Hence, for the purposes of this invention, triangular shapes also include three-sided polygons wherein one or more of the edges (parts of the perimeter of the face) can be arcuate, i.e., the definition of triangular extends to spherical triangles and the definition of quadrilaterals extends to supereliipses.

[0068] The second side may comprise a second face. The second face may have a perimeter of a second geometric shape.

[0069] The second geometric shape may be the same or be different to the first geometric shape. Preferably the second geometric shape is selected to have substantially the same shape as the first geometric shape and is preferably arranged in a congruent way with the first geometric shape (although the size or area of the geometric shapes may be different, i.e. the one face may be larger than the other one).

[0070] Examples of suitable geometric shapes include shapes as exemplified in the foregoing with respect to the first geometric shapes.

[0071] It is particularly preferred that the first and preferably also the second geometric shape is selected from triangular shapes, such as an isosceles triangular shape or, more preferably, an equilateral triangular shape.

[0072] The first face may be substantially planar or the second face (if present) may be substantially planar. Also, both faces may be substantially planar. In many typical cases, the first face is planar (and identical to the first side).

[0073] Alternatively, at least one of the first and the second face (if present) may be a non-planar face. Also both faces may be non-planar faces.

[0074] For example, one or both of the first and the second face (if present) could be recessed (or concave) or could be shaped outwardly (or be convex).

[0075] For example, the first face can be recessed (or concave) and the second face (if present) can be substantially planar. Alternatively, the first face can be shaped outwardly (or be convex) and the second face (if present) can be recessed (or concave), or, the first face can be recessed (or concave) and the second face (if present) can be recessed (or concave).

[0076] The first face and the second face (if present) can be substantially parallel to each other. Alternatively, the first face and the second face (if present) can be nonparallel, for example such that imaginary lines tangent to each face would intersect at a point (as in the exemplary case wherein one face is sloped with respect to the other face).

[0077] The second face is typically connected to the perimeter of the first face by at least one sidewall which may be a sloping sidewall, as will be discussed later in more detail. The sidewall may comprise one or more facets, which are typically selected from quadrilateral facets.

[0078] Specific examples of shaped particles having a second face include prisms (for example triangular prisms) and truncated pyramids.

[0079] In some embodiments, the second side comprises a second face and four facets that form a sidewall (draft angle alpha between the sidewall and the second face equals 90 degrees) or a sloping sidewall (draft angle alpha between the sidewall and the second face greater than 90 degrees). As the thickness, t , of the shaped abrasive particle having a sloping sidewall becomes greater, the shaped abrasive particle resembles a truncated pyramid when the draft angle alpha is greater than 90 degrees.

[0080] The shaped abrasive particles can comprise at least one sidewall, which may be a sloping sidewall. Typically, the first face and the second face are connected to each other by the at least one sidewall.

[0081] In other embodiments the ridge line and the first face are connected to each other by the at least one sidewall.

[0082] In even other embodiments, the vertex and the first face are connected to each other by the at least one sidewall.

[0083] In some embodiments, more than one (for example two or three) sloping sidewall can be present and the slope or angle for each sloping sidewall may be the same or different. In some embodiments, the first face and the second face are connected to each other by a sidewall. In other embodiments, the sidewall can be minimized for particles where the faces taper to a thin edge or point where they meet instead of having a sidewall.

[0084] The sidewall can vary and it generally forms the perimeter of the first face and the second face (if present). In case of a sloping sidewall, it forms a perimeter of the first face and a perimeter of the second face (if present). In one embodiment, the perimeter of the first face and the second face is selected to be a geometric shape (preferably a triangular shape), and the first face and the second face are selected to have the same geometric shape, although, they may differ in size with one face being larger than the other face.

[0085] A draft angle alpha between the second face and the sloping sidewall of the shaped abrasive particle can be varied to change the relative sizes of each face. In various embodiments of the invention, the area or size of the first face and the area or size of the second face are substantially equal. In other embodiments of the invention, the first face or second face can be smaller than the other face.

[0086] In one embodiment of the invention, draft angle alpha can be approximately 90 degrees such that the area of both faces are substantially equal. In another embodiment of the invention, draft angle alpha can be greater than 90 degrees such that the area of the first face is greater than the area of the second face. In another embodiment of the invention, draft angle alpha can be less than 90 degrees such that the area of the first face is less than the area of the

second face. In various embodiments of the invention, the draft angle α can be between approximately 95 degrees to approximately 130 degrees, or between about 95 degrees to about 125 degrees, or between about 95 degrees to about 120 degrees, or between about 95 degrees to about 115 degrees, or between about 95 degrees to about 110 degrees, or between about 95 degrees to about 105 degrees, or between about 95 degrees to about 100 degrees.

[0087] The first face and the second face can also be connected to each other by at least a first sloping sidewall having a first draft angle and by a second sloping sidewall having a second draft angle, which is selected to be a different value from the first draft angle. In addition, the first and second faces may also be connected by a third sloping sidewall having a third draft angle, which is a different value from either of the other two draft angles. In one embodiment, the first, second and third draft angles are all different values from each other. For example, the first draft angle could be 120 degrees, the second draft angle could be 110 degrees, and the third draft angle could be 100 degrees.

[0088] Similar to the case of an abrasive particle having one sloping sidewall, the first, second, and third sloping sidewalls of the shaped abrasive particle with a sloping sidewall can vary and they generally form the perimeter of the first face and the second face.

[0089] In general, the first, second, and third, draft angles between the second face and the respective sloping sidewall of the shaped abrasive particle can be varied with at least two of the draft angles being different values, and desirably all three being different values. In various embodiments of the invention, the first draft angle, the second draft angle, and the third draft angle can be between about 95 degrees to about 130 degrees, or between about 95 degrees to about 125 degrees, or between about 95 degrees to about 120 degrees, or between about 95 degrees to about 115 degrees, or between about 95 degrees to about 110 degrees, or between about 95 degrees to about 105 degrees, or between about 95 degrees to about 100 degrees.

[0090] The sloping sidewall can also be defined by a radius, R , instead of the draft angle α (as illustrated in Fig 5B of US Patent Application No. 2010/0151196). The radius, R , can be varied for each of the sidewalls.

[0091] Additionally, the various sloping sidewalls of the shaped abrasive particles can have the same draft angle or different draft angles. Furthermore, a draft angle of 90 degrees can be used on one or more sidewalls. However, if a shaped abrasive particle with a sloping sidewall is desired, at least one of the sidewalls is a sloping sidewall having a draft angle of about greater than 90 degrees, preferably 95 degrees or greater.

[0092] The sidewall can be precisely shaped and can be for example either concave or convex. Alternatively, the sidewall (top surface) can be uniformly planar. By uniformly planar it is meant that the sidewall does not have areas that are convex from one face to the other face, or areas that are concave from one face to the other face. For example, at least 50%, or at least 75%, or at least 85% or more of the sidewall surface can be planar. The uniformly planar sidewall provides better defined (sharper) edges where the sidewall intersects with the first face and the second face, and this is also thought to enhance grinding performance.

[0093] The sidewall may also comprise one or more facets, which are typically selected from triangular and quadrilateral facets or a combination of triangular and quadrilateral facets.

[0094] The angle β between the first side and the sidewall can be between 20 degrees to about 50 degrees, or between about 10 degrees to about 60 degrees, or between about 5 degrees to about 65 degrees.

[0095] The second side may comprise a ridge line. The ridge line is typically connected to the perimeter of the first face by at least one sidewall which may be a sloping sidewall, as discussed in the foregoing. The sidewall may comprise one or more facets, which are typically selected from triangular and quadrilateral facets or a combination of triangular and quadrilateral facets.

[0096] The ridge line may be substantially parallel to the first side. Alternatively, the ridge line may be non-parallel to the first side, for example such that an imaginary line tangent to the ridge line would intersect the first side at a point (as in the exemplary case wherein the ridge line is sloped with respect to the first face).

[0097] The ridge line may be straight lined or may be non-straight lined, as in the exemplary case wherein the ridge line comprises arcuate structures.

[0098] The facets may be planar or non-planar. For example at least one of the facets may be non-planar, such as concave or convex. In some embodiments, all of the facets can be non-planar facets, for example concave facets.

[0099] Specific examples of shaped particles having a ridge line include roof-shaped particles, for example particles as illustrated in Fig. 4A to 4C of WO 2011/068714). Preferred roof-shaped particles include particles having the shape of a hip roof, or hipped roof (a type of roof wherein any sidewalls facets present slope downwards from the ridge line to the first side. A hipped roof typically does not comprise vertical sidewall(s) or facet(s)).

[0100] In some embodiments, the first geometric shape is selected from a quadrilateral having four edges and four vertices (for example from the group consisting of a rhombus, a rhomboid, a kite, or a superellipse) and the second side comprises a ridge line and four facets forming a structure similar to a hip roof. Thus, two opposing facets will have a triangular shape and two opposing facets will have a trapezoidal shape.

[0101] The second side may comprise a vertex and at least one sidewall connecting the vertex and the perimeter of the first face. The at least one sidewall may be a sloping sidewall, as discussed in the foregoing. The sidewall may comprise one or more facets, which are typically selected from triangular facets. The facets may be planar or non-planar.

For example at least one of the facets may non-planar, such as concave or convex. In some embodiments, all of the facets can be non-planar facets, for example concave facets.

[0102] Illustrative examples include pyramidal-shaped particles, for example tetrahedral-shaped particles or particles as illustrated in Fig. 1A to 1C and Fig. 2A to 2C of WO 2011/068714.

[0103] The thickness, t , of the shaped abrasive particles can be controlled to select an angle, β , between the first side and the sidewall (or facets). In various embodiments of the invention, the angle β between the first side and the sidewall (or facets) can be between 20 degrees to about 50 degrees, or between about 10 degrees to about 60 degrees, or between about 5 degrees to about 65 degrees.

[0104] In typical embodiments the second side comprises a vertex and a sidewall comprising and more typically consisting of triangular facets forming a pyramid. The number of facets comprised by the sidewall will depend on the number of edges present in the first geometric shape (defining the perimeter of the first face). For example, pyramidal shaped abrasive particles having a first side characterized by a trilateral first geometric shape will generally have three triangular facets meeting in the vertex thereby forming a pyramid, and pyramidal shaped abrasive particles having a first side characterized by a quadrilateral first geometric shape will generally have four triangular facets meeting in the vertex thereby forming a pyramid, and so on.

[0105] In some embodiments, the second side comprises a vertex and four facets forming a pyramid. In exemplary embodiments, the first side of the shaped abrasive particle comprises a quadrilateral first face having four edges and four vertices with the quadrilateral preferably being selected from the group consisting of a rhombus, a rhomboid, a kite, or a superellipse. The shape of the perimeter of the first face (i.e., the first geometric shape) can be preferably selected from the above groups since these shapes will result in a shaped abrasive particle with opposing major vertices along the longitudinal axis and in a shape that tapers from the transverse axis toward each opposing major vertex.

[0106] The degree of taper can be controlled by selecting a specific aspect ratio for the particle as defined by the maximum length, L , along the longitudinal axis divided by the maximum width, W , along the transverse axis that is perpendicular to the longitudinal axis. This aspect ratio (also referred to herein as "secondary aspect ratio") should be greater than 1.0 for the shaped abrasive particle to taper as may be desirable in some applications. In various embodiments of the invention, the secondary aspect ratio is between about 1.3 to about 10, or between about 1.5 to about 8, or between about 1.7 to about 5. As the secondary aspect ratio becomes too large, the shaped abrasive particle can become too fragile.

[0107] In some embodiments, it is possible to slightly truncate one or more of the vertices as shown by dashed lines 42 in FIG. 1 of WO 2011/068714 and mold the shaped abrasive particles into such a configuration. In these embodiments, if the edges where the truncation occurs can be extended to form one or more imaginary vertices that then completes the claimed quadrilateral, the first side is considered to be the claimed shape. For example, if both of the major opposing vertices were truncated, the resulting shape would still be considered to be a rhombus because when the edges are extended past the truncation they form two imaginary vertices thereby completing the rhombus shape for the first side.

[0108] Another exemplary class of shaped abrasive particles having a second side comprising a vertex are tetrahedral shaped particles. A tetrahedral shape generally comprises four major sides joined by six common edges, wherein one of the four major sides contacts three other of the four major sides, and wherein the six common edges have substantially the same length. According to the definitions used herein a tetrahedral shape can be characterized by a first side comprising an equilateral triangle as a first face and a second side comprising a vertex and a sidewall comprising three equilateral triangles as facets connecting the first face and the vertex, thereby forming a tetrahedron.

[0109] At least one of the four major sides (i.e. the group consisting of the first side and the three facets) can be substantially planar. At least one of the four major sides can be concave, or all the four major sides can be concave. At least one of the four major sides can be convex or all the four major sides can be convex.

[0110] The shaped particles of this embodiment typically have tetrahedral symmetry. The shaped abrasive particles of this embodiment are preferably substantially shaped as regular tetrahedrons.

[0111] It is preferred that the shaped abrasive particles comprise at least one shape feature selected from: an opening (preferably one extending or passing through the first and second side); at least one recessed (or concave) face or facet; at least one face or facet which is shaped outwardly (or convex); at least one side comprising a plurality of grooves; a low roundness factor (as described later herein); a perimeter of the first face comprising one or more corner points having a sharp tip; a second side comprising a second face having a perimeter comprising one or more corner points having a sharp tip; or a combination of one or more of said shape features.

[0112] In preferred embodiments the shaped abrasive particles comprise at least one of the aforementioned shape features in combination with a substantially triangular shape of the perimeter of the first and optionally the second face.

[0113] In other preferred embodiments the shaped abrasive particles comprise at least one of the aforementioned shape features in combination with a substantially quadrilateral first geometric shape.

[0114] In other preferred embodiments, the shaped abrasive particle comprises a combination of two or more (for example, of three, four, five or more) of the recited shape features. For example, the abrasive particle can comprise an opening and a first face that is shaped outwardly (or convex) and a recessed (or concave) second face; a second face

comprising a plurality of grooves and a low roundness factor; or an opening and a first face that is shaped outwardly (or convex) and a recessed (or concave) second face.

[0115] The shaped abrasive particles preferably have a perimeter of the first and optionally of the second face that comprises one or more corner points having a sharp tip. Preferably, all of the corner points comprised by the perimeter(s) have sharp tips. The shaped abrasive particles preferably also have sharp tips along any edges that may be present in a sidewall (for example between two meeting facets comprised by a sidewall).

[0116] The sharpness of a corner point can be characterized by the radius of curvature along said corner point, wherein the radius extends to the interior side of the perimeter (as illustrated for the exemplary shaped abrasive particle shown in Fig. 6D).

[0117] The radius of curvature can be measured by using image analysis for example, using a CLEMEX VISION PE image analysis program available from Clemex Technologies, Inc. of Longueuil, Quebec, Canada, interfaced with an inverted light microscope, or other suitable image analysis software/equipment. Using a suitable polished cross-section taken between the first face and the second face may help in microscopic examination of the edge or corner point of a sidewall. The radius of curvature of each point of the shaped abrasive article can be determined by defining three points at the tip of each point (when viewed e.g. at 100X magnification). A point is placed at the start of the tip's curve where there is a transition from the straight edge to the start of a curve, at the apex of the tip, and at the transition from the curved tip back to a straight edge. The image analysis software then draws an arc defined by the three points (start, middle, and end of the curve) and calculates a radius of curvature. The radius of curvature for at least 30 apexes are measured and averaged to determine the average tip radius.

[0118] In various embodiments of the invention, the radius of curvature (also referred to herein as average tip radius) can be less than 75 microns, or less than 50 microns, or less than 25 microns. It is believed that a sharper edge promotes more aggressive cutting and improved fracturing of the shaped abrasive particles during use.

[0119] A smaller radius of curvature means that the particle more perfectly replicates the edge or corner features of the mold used to prepare the particle (i.e. of the ideal shape of the particle), i.e. the shaped abrasive particles are much more precisely made. Typically, shaped abrasive articles (in particular, ceramic shaped abrasive particles) made by using a mold of the desired shape provide more precisely made particles than methods based on other methods for preparing shaped abrasive particles, such as methods based on pressing, punching or extruding.

[0120] FIGS. 6C-6D show the radius of curvature 329a for sidewall edge 327a. In general, the smaller the radius of curvature, the sharper the sidewall edge will be.

[0121] The shaped abrasive particles may comprise an opening. The opening can pass completely through the first side and the second side. Alternatively, the opening can comprise a blind hole which may not pass completely through both sides.

[0122] In one embodiment, the size of the opening can be quite large relative to the area defined by the perimeter of the first face or the second face (if present).

[0123] The opening can comprise a geometric shape which may be the same or a different geometric shape than that of the first geometric shape and the second geometric shape.

[0124] An opening ratio of the opening area divided by the face area of the larger of either the first face or the second face can be between about 0.05 to about 0.95, or between about 0.1 to about 0.9, or between about 0.1 to about 0.7, between about 0.05 to about 0.5, or between about 0.05 to about 0.3. For the purposes of this calculation, the face area is based on the area enclosed by the perimeter without subtracting any area due to the opening.

[0125] Shaped abrasive particles with an opening can have several benefits over solid, shaped abrasive particles without an opening. First, the shaped abrasive particles with an opening have an enhanced cut rate as compared to solid, shaped abrasive particles. The opening can also act as a reservoir to hold more grinding aid in some embodiments. Shaped abrasive particles having a larger opening relative to the face size may have enhanced grinding performance.

[0126] The inner surface of the opening can have varying contours. For example, the contour of the inner surface may be planar, convex, or concave depending on the shape of the upstanding mold element used for the manufacture of the shaped abrasive particle with an opening. Additionally, the inner surface can be tapered such that the size of the opening in each face is different. It is preferred that the inner surface be a tapered surface such that the opening is narrower at the top of the mold cavity and wider at the bottom of the mold cavity for best release of the shaped abrasive particles from the mold and to prevent cracking of the shaped abrasive particles during drying.

[0127] The opening can be selected to have substantially the same shape as the first perimeter. The opening can also be selected to have substantially the same shape as the perimeter of the first face and of the perimeter of the second face. Thus, the shaped abrasive particles with an opening can comprise an integral connection of a plurality of bars joined at their respective ends to form a closed polygon as illustrated for example in Fig. 1A or Fig. 5A of US patent Application Publication 2010/0151201. Alternatively, the shape of the opening can be selected to be different than the shape of the first and optionally of the second perimeter, as illustrated for example in Fig. 5B of US patent Application Publication 2010/0151201. The size and/or shape of the opening can be varied to perform different functions more effectively. In one embodiment, the shape of the opening comprises a substantially triangular shape, more preferably

the shape of an equilateral triangle.

[0128] Another feature of the shaped abrasive particles with an opening can be an extremely low bulk density as tested by ANSI B74.4-1992 Procedure for Bulk Density of Abrasive Grains. Since the opening can significantly reduce the mass of the shaped abrasive particles without reducing their overall size, the resulting bulk density can be extremely low. Moreover, the bulk density of the shaped abrasive particles can be readily changed and controlled by simply varying the size and shape of the opening in the particles. In various embodiments of the invention, the bulk density of the shaped abrasive particles with an opening can be less than 1.35 g/cm³, or less than 1.20 g/cm³, or less than 1.00 g/cm³, or less than 0.90 g/cm³.

[0129] The shaped abrasive particles may comprise at least one non-planar face. For example, the first face may be a non-planar face or the first face and the second face may be a non-planar faces, or one or both of the first face and the second face could be recessed (or concave) or shaped outwardly (or be convex).

[0130] For example, the first face can be recessed (or concave) and the second face can be substantially planar. Alternatively, the first face can be convex and the second face can be recessed (or concave), or, the first face can be recessed (or concave) and the second face can be recessed (or concave).

[0131] A recessed face may comprise a substantially planar center portion and a plurality of raised corners or upturned points. To further characterize a recessed face, the curvature of the first face of the shaped abrasive particles can be measured by fitting a sphere using a suitable image analysis program such as a non-linear regression curve-fitting program "NLREG", available from Phillip Sherrod, Brentwood, Tenn., obtained from www.NLREG.com. A recessed face may comprise a radius of a sphere curve fitted to the recessed face by image analysis. The radius can be between about 1 mm to about 25 mm, more preferably about 1 mm to about 14 mm or between about 2 mm to about 7 mm, when the center of the sphere is vertically aligned above the midpoint of the first face 24. In one embodiment, the radius of the fitted sphere to the dish-shaped abrasive particles measured 2.0 mm, in another embodiment 3.2 mm, in another embodiment 5.3 mm, and in another embodiment 13.7 mm.

[0132] In one embodiment, the abrasive particles may be described as dish-shaped abrasive particles. In general, the dish-shaped abrasive particles comprise thin bodies having a first face, and a second face separated by a sidewall having a varying thickness t . In general, the sidewall thickness is greater at the points or corners of the dish-shaped abrasive particles and thinner at the midpoints of the edges. As such, T_m is less than T_c . In some embodiments, the sidewall is a sloping sidewall having a draft angle α greater than 90 degrees as discussed in more detail in the foregoing. More than one sloping sidewall can be present and the slope or draft angle for each sloping sidewall may be the same or different for each side of the dish-shaped abrasive particle, as discussed in the foregoing.

[0133] In some embodiments, the first face is recessed and the second face and sidewall are substantially planar. By recessed it is meant that the thickness of the interior of the first face, T_i , is thinner than the thickness of the shaped abrasive particle at portions along the perimeter.

[0134] As mentioned, in some embodiments, the recessed face can have a substantially flat center portion and a plurality of upturned points or a plurality of raised corners. The perimeter of the dish-shaped abrasive particle can be flat or straight at portions between the upturned points or corners and the thickness T_c can be much greater than T_m .

[0135] In other embodiments, the recessed first face is substantially concave with three upturned points or corners and a substantially planar second face (the shaped abrasive particle is plano-concave). The difference between T_c and T_m is less and there can be a more gradual transition from the interior of the first face to each upturned point as compared to the embodiment wherein the first face is recessed and the second face and sidewall are substantially planar. A recessed face may be the result from the use of a manufacturing method involving sol-gel in a mold cavity and forming a meniscus leaving the first face recessed. As mentioned, the first face can be recessed such that the thickness, T_c , at the points or corners tends to be greater than the thickness, T_i , of the interior of the first face. As such, the points or corners are elevated higher than the interior of the first face.

[0136] In various embodiments of the invention, a thickness ratio of T_c/T_i can be between 1.25 to 5.00, or between 1.30 to 4.00, or between 1.30 to 3.00. The thickness ratio can be calculated as described in [0036] of US Patent Application Publication No. 2010/0151195. Triangular dish-shaped abrasive particles have been measured to have thickness ratios between 1.55 to 2.32 in some embodiments. Triangular shaped particles produced by the prior art method disclosed in U.S. Pat. No. 5,366,523 (Rowenhorst et al.) have been measured to have thickness ratios between 0.94 to 1.15 meaning they are essentially flat and are just as likely to be slightly thicker in the middle as they are to be slightly thinner in the middle. Dish-shaped abrasive particles having a thickness ratio greater than 1.20 are statistically different from the Rowenhorst particles at the 95% confidence interval.

[0137] One or more draft angle(s) α between the second face and the sidewall of the dish-shaped abrasive particle can be varied to change the relative sizes of each face as described in the foregoing.

[0138] A preferred embodiment of a dish-shaped abrasive particle is one with a recessed face. The draft angle α is approximately 98 degrees and the dish-shaped abrasive particle's perimeter comprises an equilateral triangle. The sides of each triangle measured approximately 1.4 mm long at the perimeter of the first face.

[0139] In one embodiment the thickness t can be more uniform. As such, T_m can be approximately equal to T_c .

[0140] In one embodiment, the first face is convex and the second face is concave (concavo-convex), for example such that the dish-shaped abrasive particle substantially comprises a triangular section of a spherical shell.

[0141] It is believed that the convex face is formed by the sol-gel in the mold cavity releasing from the bottom surface of the mold due to the presence of a mold release agent such as peanut oil during evaporative drying of the sol-gel. The rheology of the sol-gel then results in the convex/concave formation of the first and second face while the perimeter is formed into shape (preferably, a triangular shape) during evaporative drying.

[0142] In various embodiments of the invention, the radius of a sphere fitted to the concave second face can be between about 1 mm to about 25 mm, or between about 1 mm to about 14 mm, or between about 2 mm to about 7 mm, when the center of the sphere is vertically aligned above the midpoint of the second face.

[0143] In other embodiments of the invention, the first face and the second face of the dish-shaped abrasive particles can both be recessed. In some embodiments, the dish-shaped abrasive particles can be biconcave having a concave first face and a concave second face. Alternatively, other recessed structural geometries can be formed on the second face. For example, a plurality of upturned points or a plurality of raised corners on the second face. In such embodiments, the degree of curvature or flatness of the first face can be controlled to some extent by how the dish-shaped abrasive particles are dried thereby resulting in a recessed or curved first face or a substantially planar first face.

[0144] The shaped abrasive particles can comprise a plurality of grooves on one or both of the first side and the second side. Preferably, the second side (i.e., one or more sidewalls, faces or facets comprised by the second side, and more preferably the second face) comprises a plurality of grooves.

[0145] The shaped abrasive particles can comprise a plurality of ridges on one or both of the first side and the second side. Preferably, the second side (i.e., one or more sidewalls, faces or facets comprised by the second side, and more preferably the second face) comprises a plurality of ridges.

[0146] The plurality of grooves (or ridges) can be formed by a plurality of ridges (or grooves) in the bottom surface of a mold cavity that have been found to make it easier to remove the precursor shaped abrasive particles from the mold.

[0147] The plurality of grooves (or ridges) is not particularly limited and can, for example, comprise parallel lines which may or may not extend completely across the side. In terms of this aspect ratio, the shaped abrasive particles for use in the invention can be characterized as having a ratio of the length of the greatest cross-sectional dimension, of from about 2:1 to about 50:1 and more typically greater than about 5:1 to about 25:1. In one embodiment, the plurality of grooves (or ridges) comprises parallel lines extending completely across the second side (preferably across the second face). Preferably, the parallel lines intersect with the perimeter along a first edge at a 90 degree angle. The cross sectional geometry of a groove or ridge can be a truncated triangle, triangle, or other geometry as further discussed in the following. In various embodiments of the invention, the depth, D, of the plurality of grooves can be between about 1 micrometer to about 400 micrometers. Furthermore, a percentage ratio of the groove depth, D, to the dish-shaped abrasive particle's thickness, Tc, (D/Tc expressed as a percent) can be between about 0.1% to about 30%, or between about 0.1% to 20%, or between about 0.1% to 10%, or between about 0.5% to about 5%.

[0148] In various embodiments of the invention, the spacing between each groove (or ridge) can be between about 1% to about 50%, or between about 1% to 40%, or between about 1% to 30%, or between about 1% to 20%, or between about 5% to 20% of a face dimension such as the length of one of the edges of the dish-shaped abrasive particle.

[0149] According to another embodiment the plurality of grooves comprises a cross hatch pattern of intersecting parallel lines which may or may not extend completely across the face. A first set of parallel lines intersects one edge of the perimeter at a 90 degree angle (having a percent spacing of for example 6.25%) of the edge length of the triangle, and a second set of parallel lines intersects a second edge of the perimeter at a 90 degree angle (having a percent spacing of for example 6.25%) creating the cross hatch pattern and forming a plurality of raised diamonds in the second face. In various embodiments, the cross hatch pattern can use intersecting parallel or non-parallel lines, various percent spacing between the lines, arcuate intersecting lines, or various cross-sectional geometries of the grooves.

[0150] In other embodiments of the invention the number of ridges (or grooves) in the bottom surface of each mold cavity can be between 1 and about 100, or between 2 to about 50, or between about 4 to about 25 and thus form a corresponding number of grooves (or ridges) in the shaped abrasive particles.

[0151] The shaped abrasive particles may have a low Roundness Factor. Such shaped abrasive particles comprise a longitudinal axis extending from a base to the grinding tip of the abrasive article (for example, as shown in Fig. 1 of US Patent Application Publication No. 2010/0319269).

[0152] The Roundness Factor can be determined as described in [0029] to [0033] of US Patent Application Publication No. 2010/0319269 by using a transverse cut C, as defined in [0029] of said patent application publication.

[0153] The Average Roundness Factor for the shaped abrasive particles can be between about 15% to 0%, or between about 13% to 0%, or between about 12% to 0%, or between about 12% to about 5%.

[0154] The geometric shape of the cross-sectional plane resulting from the transverse cut (i.e., the cut transversely at 90 degrees to the longitudinal axis) of the shaped abrasive particles can also vary. A non-circular cross-sectional shape is most preferably used. A circular cross-sectional shape is round, which is believed to be duller. It is believed that a non-circular cross-sectional shape has improved grinding performance since one or more sharp corners can be

present and one or more sides could be generally linear similar to a chisel blade. Desirably, the cross-sectional shape is a polygonal shape, including but not limited to, a triangle, a rectangle, a trapezoid, or a pentagon.

[0155] In one embodiment, the perimeter of the shaped abrasive particle is triangular and the cross-sectional shape is trapezoidal.

[0156] Another embodiment is a shaped abrasive particle respectively bounded by a polygonal first face (or base), a polygonal second face (or top), and a plurality of sidewalls connecting the base and the top, wherein adjacent sidewalls meet at respective sidewall edges having an average radius of curvature of less than 50 micrometers. For example, referring to FIGS. 6A-6B, exemplary shaped abrasive particle 320 is bounded by a trigonal base 321, a trigonal top 323, and plurality of sidewalls 325a, 325b, 325c connecting base 321 and top 323. Base 321 has sidewall edges 327a, 327b, 327c, having an average radius of curvature of less than 50 micrometers. FIGS. 6C-6D show radius of curvature 329a for sidewall edge 327a. In general, the smaller the radius of curvature, the sharper the sidewall edge will be. Typically, the base and the top of the shaped abrasive particles are substantially parallel, resulting in prismatic or truncated pyramidal (as shown in FIGS. 6A-6B) shapes, although this is not a requirement. As shown, sides 325a, 325b, 325c have equal dimensions and form dihedral angles with base 321 of about 82 degrees. However, it will be recognized that other dihedral angles (including 90 degrees) may also be used. For example, the dihedral angle between the base and each of the sidewalls may independently range from 45 to 90 degrees, typically 70 to 90 degrees, more typically 75 to 85 degrees.

[0157] The shaped abrasive particles used in the present invention can have an abrasives industry specified nominal grade or a nominal screened grade.

[0158] Abrasive particles are generally graded to a given particle size distribution before use. Such distributions typically have a range of particle sizes, from coarse particles to fine particles. In the abrasive art this range is sometimes referred to as a "coarse", "control", and "fine" fractions. Abrasive particles graded according to abrasive industry accepted grading standards specify the particle size distribution for each nominal grade within numerical limits. Such industry accepted grading standards (i.e., abrasive industry specified nominal grade) include those known as the American National Standards Institute, Inc. (ANSI) standards, Federation of European Producers of Abrasive Products (FEPA) standards, and Japanese Industrial Standard (JIS) standards.

[0159] ANSI grade designations (i.e., specified nominal grades) include: ANSI 4, ANSI 6, ANSI 8, ANSI 16, ANSI 24, ANSI 36, ANSI 46, ANSI 54, ANSI 60, ANSI 70, ANSI 80, ANSI 90, ANSI 100, ANSI 120, ANSI 150, ANSI 180, ANSI 220, ANSI 240, ANSI 280, ANSI 320, ANSI 360, ANSI 400, and ANSI 600. FEPA grade designations include F4, F5, F6, F7, F8, F10, F12, F14, F16, F16, F20, F22, F24, F30, F36, F40, F46, F54, F60, F70, F80, F90, F100, F120, F150, F180, F220, F230, F240, F280, F320, F360, F400, F500, F600, F800, F1000, F1200, F1500, and F2000. JIS grade designations include JIS8, JIS12, JIS16, JIS24, JIS36, JIS46, JIS54, JIS60, JIS80, JIS100, JIS150, JIS180, JIS220, JIS240, JIS280, JIS320, JIS360, JIS400, JIS600, JIS800, JIS1000, JIS1500, JIS2500, JIS4000, JIS6000, JIS8000, and JIS10,000.

[0160] Alternatively, the shaped abrasive particles can be graded to a nominal screened grade using U.S.A. Standard Test Sieves conforming to ASTM E-11 "Standard Specification for Wire Cloth and Sieves for Testing Purposes." ASTM E-11 proscribes the requirements for the design and construction of testing sieves using a medium of woven wire cloth mounted in a frame for the classification of materials according to a designated particle size. A typical designation may be represented as -18+20 meaning that the shaped abrasive particles pass through a test sieve meeting ASTM E-11 specifications for the number 18 sieve and are retained on a test sieve meeting ASTM E-11 specifications for the number 20 sieve. In one embodiment, the shaped abrasive particles have a particle size such that most of the particles pass through an 18 mesh test sieve and can be retained on a 20, 25, 30, 35, 40, 45, or 50 mesh test sieve. In various embodiments of the invention, the shaped abrasive particles can have a nominal screened grade comprising: -18+20, -20+25, -25+30, -30+35, -35+40, -40+45, -45+50, -50+60, -60+70, -70+80, -80+100, -100+120, -120+140, -140+170, -170+200, -200+230, -230+270, -270+325, -325+400, -400+450, -450+500, or -500+635.

[0161] According to any of claims 5 to 12, the shaped abrasive particles and the secondary abrasive particles are comprised in a blend, wherein the content of the secondary abrasive particles is up to 95% by weight based on the total amount of abrasive particles present in the blend. In another embodiment, the article does not contain secondary abrasive particles.

[0162] In some embodiments, at least 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, or even 100 percent by weight of a plurality of abrasive particles are shaped abrasive particles according to the present invention, based on the total weight of the plurality of abrasive particles. The plurality may have an abrasives industry specified nominal grade or a nominal screened grade.

[0163] Methods to provide shaped abrasive particles are known in the art and include technologies based on (1) fusion, (2) sintering, and (3) chemical ceramic. While preferred shaped abrasive particles can be obtained by using chemical ceramic technology, non-ceramic shaped abrasive particles are also included within the scope of the present invention. In the description of the invention, methods for preparing shaped abrasive particles may be described with specific reference to ceramic shaped abrasive particles, particularly alumina based ceramic shaped abrasive particles. It is to

be understood however that the invention is not limited to alumina but is capable of being adapted for use with a plurality of different hard and superhard materials.

[0164] The shaped abrasive particles used in the present invention can typically be made using tools (i.e., molds), cut using diamond tooling, which provides higher feature definition than other fabrication alternatives such as, for example, stamping or punching. Typically, the cavities in the tool surface have planar faces that meet along sharp edges, and form the sides and top of a truncated pyramid. The resultant shaped abrasive particles have a respective nominal average shape that corresponds to the shape of cavities (e.g., truncated pyramid) in the tool surface; however, variations (e.g., random variations) from the nominal average shape may occur during manufacture, and shaped abrasive particles exhibiting such variations are included within the definition of shaped abrasive particles as used herein.

[0165] Shaped abrasive particles (for example alpha-alumina based ceramic particles) can be made according to a multistep process typically using a dimensionally stable dispersion of a suitable precursor (for example a ceramic precursor).

[0166] The dispersion that is typically employed in the process may be any dispersion of a suitable precursor and by this is intended a finely dispersed material that, after being subjected to a process suitable in the invention, is in the form of a shaped abrasive particle. The precursor may be chemically a precursor, as for example boehmite is a chemical precursor of alpha alumina; a morphological precursor as for example gamma alumina is a morphological precursor of alpha alumina; as well as (or alternatively), physically a precursor in the sense of that a finely divided form of alpha alumina can be formed into a shape and sintered to retain that shape. In typical cases, the dimensionally stable dispersion of a suitable precursor is a sol-gel.

[0167] Where the dispersion comprises a physical or morphological precursor as the term is used herein, the precursor is in the form of finely divided powder grains that, when sintered together, form an abrasive particle of utility in conventional bonded and coated abrasive applications. Such materials generally comprise powder grains with an average size of less than about 20 microns, preferably less than about 10 microns and most preferably less than about a micron. The solids content of a dispersion of a physical or a morphological precursor is preferably from about 40 to 65% though higher solids contents of up to about 80% can be used. An organic compound is frequently used along with the finely divided grains in such dispersions as a suspending agent or perhaps as a temporary binder until the particle has been dried sufficiently to maintain its shape. This can be any of those generally known for such purposes such as polyethylene glycol, sorbitan esters and the like.

[0168] The solids content of a chemical precursor that changes to its final stable (for example, ceramic) form upon heating may need to take into account water that may be liberated from the precursor during drying and firing to sinter the particles. In such cases the solids content is typically somewhat lower such as about 75% or lower and more preferably between about 30% and about 50%. With a boehmite gel a maximum solids content of about 60% or even 40% is preferred and a gel with a peptized minimum solids content of about 20% may also be used.

[0169] Particles made from physical precursors will typically need to be fired at higher temperatures than those formed from a seeded chemical precursor. For example, whereas particles of a seeded boehmite gel form an essentially fully densified alpha alumina at temperatures below about 1250°C, particles made from alpha alumina gels require a firing temperature of above about 1400°C for full densification.

[0170] By way of example, a method suitable for use in the present invention comprises chemical ceramic technology involving converting a colloidal dispersion or hydrosol (sometimes called a sol), optionally in a mixture with solutions of other metal oxide precursors, to a gel or any other physical state that restrains the mobility of the components, drying, and firing to obtain a ceramic material. A sol can be prepared by any of several methods, including precipitation of a metal hydroxide from an aqueous solution followed by peptization, dialysis of anions from a solution of metal salt, solvent extraction of an anion from a solution of a metal salt, hydrothermal decomposition of a solution of a metal salt having a volatile anion. The sol optionally contains metal oxide or precursor thereof and is transformed to a semi-rigid solid state of limited mobility such as a gel by, e.g., partial extraction of the solvent, e.g., water, the gel can be shaped by any convenient method such as pressing, molding, or extruding, to provide a shaped abrasive grain.

[0171] An exemplary method involving chemical ceramic technology comprises the steps of making a dimensionally stable dispersion of a ceramic precursor (which may for example include either a seeded or non-seeded sol-gel alpha alumina precursor dispersion that can be converted into alpha alumina); filling one or more mold cavities having the desired outer shape of the shaped abrasive particle with the dimensionally stable dispersion of a ceramic precursor, drying the stable dispersion of a ceramic precursor to form precursor ceramic shaped abrasive particles; removing the precursor ceramic shaped abrasive particles from the mold cavities; calcining the precursor ceramic shaped abrasive particles to form calcined, precursor ceramic shaped abrasive particles, and then sintering the calcined, precursor ceramic shaped abrasive particles to form ceramic shaped abrasive particles. The process is described in more detail in U.S. Patent No. 5,201,916 (Berg et al.).

[0172] The materials that can be made into shaped particles of the invention include physical precursors such as finely divided particles of known ceramic materials, carbides, nitrides such as alpha alumina, tungsten carbide, silicon carbide, titanium nitride, alumina/zirconia and cubic boron nitride (CBN). Also included are chemical and/or morphological pre-

cursors such as aluminum trihydrate, boehmite, gamma alumina and other transitional aluminas and bauxite. The most useful of the above are typically based on alumina, and its physical or chemical precursors and in the specific descriptions that follow a method suitable for use in the invention is illustrated with specific reference to alumina.

[0173] Other components that have been found to be desirable in certain circumstances for the production of alumina-based particles include nucleating agents such as finely divided alpha alumina, ferric oxide, chromium oxide and other materials capable of nucleating the transformation of precursor forms to the alpha alumina form; oxide of magnesium; titanium; zirconium; yttrium; and rare earth metal oxides. Such additives often act as crystal growth limiters or boundary phase modifiers. The amount of such additives in the precursor is usually less than about 10% and often less than 5% by weight (solids basis).

[0174] It is also possible to use, instead of a chemical or morphological precursor of alpha alumina, a slip of finely divided alpha alumina itself together with an organic compound that will maintain it in suspension and act as a temporary binder while the particle is being fired to essentially full densification. In such cases it is often possible to include in the suspension materials that will form a separate phase upon firing or that can act as an aid in maintaining the structural integrity of the shaped particles either during drying and firing, or after firing. Such materials may be present as impurities. If for example the precursor is finely divided bauxite, there will be a small proportion of vitreous material present that will form a second phase after the powder grains are sintered together to form the shaped particle.

[0175] Ceramic shaped abrasive particles composed of crystallites of alpha alumina, magnesium alumina spinel, and a rare earth hexagonal aluminate may also be used. Such particles may be prepared using sol-gel precursor alpha alumina particles according to methods described in, for example, U.S. Patent No. 5,213,591 (Celikkaya et al.) and U.S. Publ. Patent Appl. Nos. 2009/0165394 A1 (Culler et al.) and 2009/0169816 A1 (Erickson et al.).

[0176] In some embodiments, ceramic shaped abrasive particles can be made according to a multistep process. The process will now be described in greater detail with specific reference to alumina. Generally, alpha alumina based shaped abrasive particles can be made from a dispersion of aluminum oxide monohydrate that is gelled, molded to shape, dried to retain the shape, calcined, and sintered as is known in the art. The shaped abrasive particle's shape is retained without the need for a binder.

[0177] The first process step of the multi-step process involves providing either a seeded or non-seeded dispersion of an alpha alumina precursor that can be converted into alpha alumina. The alpha alumina precursor dispersion often comprises a liquid that is a volatile component. In one embodiment, the volatile component is water. The dispersion should comprise a sufficient amount of liquid for the viscosity of the dispersion to be sufficiently low to enable filling mold cavities and replicating the mold surfaces, but not so much liquid as to cause subsequent removal of the liquid from the mold cavity to be prohibitively expensive. In one embodiment, the alpha alumina precursor dispersion comprises from 2 percent to 90 percent by weight of the particles that can be converted into alpha alumina, such as particles of aluminum oxide monohydrate (boehmite), and at least 10 percent by weight, or from 50 percent to 70 percent, or 50 percent to 60 percent, by weight of the volatile component such as water. Conversely, the alpha alumina precursor dispersion in some embodiments contains from 30 percent to 50 percent, or 40 percent to 50 percent, by weight solids.

[0178] Aluminum oxide hydrates other than boehmite can also be used. Boehmite can be prepared by known techniques or can be obtained commercially. Examples of commercially available boehmite include products having the trade designations "DISPERAL", and "DISPAL", both available from Sasol North America, Inc. of Houston, Texas, or "HiQ-40" available from BASF Corporation of Florham Park, New Jersey. These aluminum oxide monohydrates are relatively pure; that is, they include relatively little, if any, hydrate phases other than monohydrates, and have a high surface area.

[0179] The physical properties of the resulting ceramic shaped abrasive particles will generally depend upon the type of material used in the alpha alumina precursor dispersion. In one embodiment, the alpha alumina precursor dispersion is in a gel state. As used herein, a "gel" is a three dimensional network of solids dispersed in a liquid.

[0180] The alpha alumina precursor dispersion may contain a modifying additive or precursor of a modifying additive. The modifying additive can function to enhance some desirable property of the abrasive particles or increase the effectiveness of the subsequent sintering step. Modifying additives or precursors of modifying additives can be in the form of soluble salts, typically water soluble salts. They typically consist of a metal-containing compound and can be a precursor of oxide of magnesium, zinc, iron, silicon, cobalt, nickel, zirconium, hafnium, chromium, yttrium, praseodymium, samarium, ytterbium, neodymium, lanthanum, gadolinium, cerium, dysprosium, erbium, titanium, and mixtures thereof. The particular concentrations of these additives that can be present in the alpha alumina precursor dispersion can be varied based on skill in the art.

[0181] Typically, the introduction of a modifying additive or precursor of a modifying additive will cause the alpha alumina precursor dispersion to gel. The alpha alumina precursor dispersion can also be induced to gel by application of heat over a period of time. The alpha alumina precursor dispersion can also contain a nucleating agent (seeding) to enhance the transformation of hydrated or calcined aluminum oxide to alpha alumina. Nucleating agents suitable for this invention include fine particles of alpha alumina, alpha ferric oxide or its precursor, titanium oxides and titanates, chrome oxides, or any other material that will nucleate the transformation. The amount of nucleating agent, if used, should be sufficient to effect the transformation of alpha alumina. Nucleating such alpha alumina precursor dispersions

is disclosed in U.S. Patent No. 4,744,802 (Schwabel).

[0182] A peptizing agent can be added to the alpha alumina precursor dispersion to produce a more stable hydrosol or colloidal alpha alumina precursor dispersion. Suitable peptizing agents are monoprotic acids or acid compounds such as acetic acid, hydrochloric acid, formic acid, and nitric acid. Multiprotic acids can also be used but they can rapidly gel the alpha alumina precursor dispersion, making it difficult to handle or to introduce additional components thereto. Some commercial sources of boehmite contain an acid titer (such as absorbed formic or nitric acid) that will assist in forming a stable alpha alumina precursor dispersion.

[0183] The alpha alumina precursor dispersion can be formed by any suitable means, such as, for example, by simply mixing aluminum oxide monohydrate with water containing a peptizing agent or by forming an aluminum oxide monohydrate slurry to which the peptizing agent is added.

[0184] Defoamers or other suitable chemicals can be added to reduce the tendency to form bubbles or entrain air while mixing. Additional chemicals such as wetting agents, alcohols, or coupling agents can be added if desired. The alpha alumina abrasive particles may contain silica and iron oxide as disclosed in U.S. Patent No. 5,645,619 (Erickson et al.). The alpha alumina abrasive particles may contain zirconia as disclosed in U.S. Patent No. 5,551,963 (Larmie). Alternatively, the alpha alumina abrasive particles can have a microstructure or additives as disclosed in U.S. Patent No. 6,277,161 (Castro).

[0185] The second process step involves providing a mold having at least one mold cavity, and preferably a plurality of cavities. The mold can have a generally planar bottom surface and a plurality of mold cavities. The plurality of cavities can be formed in a production tool. The production tool can be a belt, a sheet, a continuous web, a coating roll such as a rotogravure roll, a sleeve mounted on a coating roll, or die. In one embodiment, the production tool comprises polymeric material. Examples of suitable polymeric materials include thermoplastics such as polyesters, polycarbonates, poly(ether sulfone), poly(methyl methacrylate), polyurethanes, polyvinylchloride, polyolefin, polystyrene, polypropylene, polyethylene or combinations thereof, or thermosetting materials. In one embodiment, the entire tooling is made from a polymeric or thermoplastic material. In another embodiment, the surfaces of the tooling in contact with the sol-gel while drying, such as the surfaces of the plurality of cavities, comprises polymeric or thermoplastic materials and other portions of the tooling can be made from other materials. A suitable polymeric coating may be applied to a metal tooling to change its surface tension properties by way of example.

[0186] A polymeric or thermoplastic tool can be replicated off a metal master tool. The master tool will have the inverse pattern desired for the production tool. The master tool can be made in the same manner as the production tool. In one embodiment, the master tool is made out of metal, e.g., nickel and is diamond turned. The polymeric sheet material can be heated along with the master tool such that the polymeric material is embossed with the master tool pattern by pressing the two together. A polymeric or thermoplastic material can also be extruded or cast onto the master tool and then pressed. The thermoplastic material is cooled to solidify and produce the production tool. If a thermoplastic production tool is utilized, then care should be taken not to generate excessive heat that may distort the thermoplastic production tool limiting its life. More information concerning the design and fabrication of production tooling or master tools can be found in U.S. Patent Nos. 5,152,917 (Pieper et al.); 5,435,816 (Spurgeon et al.); 5,672,097 (Hoopman et al.); 5,946,991 (Hoopman et al.); 5,975,987 (Hoopman et al.); and 6,129,540 (Hoopman et al.).

[0187] Access to cavities can be from an opening in the top surface or bottom surface of the mold. In some instances, the cavities can extend for the entire thickness of the mold. Alternatively, the cavities can extend only for a portion of the thickness of the mold. In one embodiment, the top surface is substantially parallel to bottom surface of the mold with the cavities having a substantially uniform depth. At least one side of the mold, that is, the side in which the cavities are formed, can remain exposed to the surrounding atmosphere during the step in which the volatile component is removed.

[0188] The cavities have a specified three-dimensional shape to make the ceramic shaped abrasive particles. The depth dimension is equal to the perpendicular distance from the top surface to the lowermost point on the bottom surface. The depth of a given cavity can be uniform or can vary along its length and/or width. The cavities of a given mold can be of the same shape or of different shapes.

[0189] The third process step involves filling the cavities in the mold with the alpha alumina precursor dispersion (e.g., by a conventional technique). In some embodiments, a knife roll coater or vacuum slot die coater can be used. A mold release can be used to aid in removing the particles from the mold if desired. Typical mold release agents include oils such as peanut oil or mineral oil, fish oil, silicones, polytetrafluoroethylene, zinc stearate, and graphite. In general, mold release agent such as peanut oil, in a liquid, such as water or alcohol, is applied to the surfaces of the production tooling in contact with the sol-gel such that between about 0.1 mg/in² (0.02 mg/cm²) to about 3.0 mg/in² (0.46 mg/cm²), or between about 0.1 mg/in² (0.02 mg/cm²) to about 5.0 mg/in² (0.78 mg/cm²) of the mold release agent is present per unit area of the mold when a mold release is desired. In some embodiments, the top surface of the mold is coated with the alpha alumina precursor dispersion. The alpha alumina precursor dispersion can be pumped onto the top surface.

[0190] Next, a scraper or leveler bar can be used to force the alpha alumina precursor dispersion fully into the cavity of the mold. The remaining portion of the alpha alumina precursor dispersion that does not enter cavity can be removed from top surface of the mold and recycled. In some embodiments, a small portion of the alpha alumina precursor

dispersion can remain on the top surface and in other embodiments the top surface is substantially free of the dispersion. The pressure applied by the scraper or leveler bar is typically less than 100 psi (0.7 MPa), less than 50 psi (0.3 MPa), or even less than 10 psi (69 kPa). In some embodiments, no exposed surface of the alpha alumina precursor dispersion extends substantially beyond the top surface to ensure uniformity in thickness of the resulting ceramic shaped abrasive particles.

[0191] The fourth process step involves removing the volatile component to dry the dispersion. Desirably, the volatile component is removed by fast evaporation rates. In some embodiments, removal of the volatile component by evaporation occurs at temperatures above the boiling point of the volatile component. An upper limit to the drying temperature often depends on the material the mold is made from. For polypropylene tooling the temperature should be less than the melting point of the plastic. In one embodiment, for a water dispersion of between about 40 to 50 percent solids and a polypropylene mold, the drying temperatures can be between about 90°C to about 165°C, or between about 105°C to about 150°C, or between about 105°C to about 120°C. Higher temperatures can lead to improved production speeds but can also lead to degradation of the polypropylene tooling limiting its useful life as a mold.

[0192] The fifth process step involves removing resultant precursor ceramic shaped abrasive particles with from the mold cavities. The precursor ceramic shaped abrasive particles can be removed from the cavities by using the following processes alone or in combination on the mold: gravity, vibration, ultrasonic vibration, vacuum, or pressurized air to remove the particles from the mold cavities.

[0193] The precursor abrasive particles can be further dried outside of the mold. If the alpha alumina precursor dispersion is dried to the desired level in the mold, this additional drying step is not necessary. However, in some instances it may be economical to employ this additional drying step to minimize the time that the alpha alumina precursor dispersion resides in the mold. Typically, the precursor ceramic shaped abrasive particles will be dried from 10 to 480 minutes, or from 120 to 400 minutes, at a temperature from 50°C to 160°C, or at 120°C to 150°C.

[0194] The sixth process step involves calcining the precursor ceramic shaped abrasive particles. During calcining, essentially all the volatile material is removed, and the various components that were present in the alpha alumina precursor dispersion are transformed into metal oxides. The precursor ceramic shaped abrasive particles are generally heated to a temperature from 400°C to 800°C, and maintained within this temperature range until the free water and over 90 percent by weight of any bound volatile material are removed. In an optional step, it may be desired to introduce the modifying additive by an impregnation process. A water-soluble salt can be introduced by impregnation into the pores of the calcined, precursor ceramic shaped abrasive particles. Then the precursor ceramic shaped abrasive particles are fired again. This option is further described in U.S. Patent No. 5,164,348 (Wood).

[0195] The seventh process step involves sintering the calcined, precursor ceramic shaped abrasive particles to form alpha alumina particles. Prior to sintering, the calcined, precursor ceramic shaped abrasive particles are not completely densified and thus lack the desired hardness to be used as ceramic shaped abrasive particles. Sintering takes place by heating the calcined, precursor ceramic shaped abrasive particles to a temperature of from 1000°C to 1650°C and maintaining them within this temperature range until substantially all of the alpha alumina monohydrate (or equivalent) is converted to alpha alumina and the porosity is reduced to less than 15 percent by volume. The length of time to which the calcined, precursor ceramic shaped abrasive particles must be exposed to the sintering temperature to achieve this level of conversion depends upon various factors but usually from five seconds to 48 hours is typical.

[0196] In another embodiment, the duration for the sintering step ranges from one minute to 90 minutes. After sintering, the ceramic shaped abrasive particles can have a Vickers hardness of 10 GPa, 16 GPa, 18 GPa, 20 GPa, or greater.

[0197] Other steps can be used to modify the described process such as, for example, rapidly heating the material from the calcining temperature to the sintering temperature, centrifuging the alpha alumina precursor dispersion to remove sludge and/or waste. Moreover, the process can be modified by combining two or more of the process steps if desired. Conventional process steps that can be used to modify the process of this disclosure are more fully described in U.S. Patent No. 4,314,827 (Leitheiser). More information concerning methods to make ceramic shaped abrasive particles is disclosed in US Patent Application Publication No. 2009/0165394 A1 (Culler et al.).

[0198] Methods for making shaped abrasive particles having at least one sloping sidewall are for example described in US Patent Application Publication Nos. 2010/0151196 and 2009/0165394. Methods for making shaped abrasive particles having an opening are for example described in US Patent Application Publication No. 2010/0151201 and 2009/0165394. Methods for making shaped abrasive particles having grooves on at least one side are for example described in US Patent Application Publication No. 2010/0146867. Methods for making dish-shaped abrasive particles are for example described in US Patent Application Publication Nos. 2010/0151195 and 2009/0165394. Methods for making shaped abrasive particles with low Roundness Factor are for example described in US Patent Application Publication No. 2010/0319269. Methods for making shaped abrasive particles with at least one fractured surface are for example described in US Patent Application Publication Nos. 2009/0169816 and 2009/0165394. Methods for making abrasive particles wherein the second side comprises a vertex (for example, dual tapered abrasive particles) or a ridge line (for example, roof shaped particles) are for example described in WO 2011/068714.

[0199] The bonding medium of a bonded abrasive article serves to retain the shaped abrasive particles (and any

optional components, such as secondary abrasive particles, fillers and additives) in the abrasive article. According to the present invention, the bonding medium comprises a vitreous (also referred to as vitrified) bond phase. In a preferred embodiment, the bonding medium is a vitreous bond (phase). The vitreous bond serves to retain the shaped abrasive particles (and any optional secondary abrasive particles as described later herein) in the article. The vitreous bond phase which binds together the abrasive particles (shaped abrasive particle and any optional secondary abrasive particles) is as defined in claim 1 and can be of any suitable composition.

[0200] The vitreous bond phase, also known in the art as a "vitrified bond", "vitreous bond", "ceramic bond" or "glass bond", may be produced from a vitreous bond precursor composition comprising a mixture or combination of one or more raw materials that when heated to a high temperature melt and/or fuse to form an integral vitreous matrix phase.

[0201] Typical raw materials for forming a vitreous bond phase can be selected from metal oxides (including metalloid oxides), non-metal oxides, non-metal compounds, silicates and naturally occurring and synthetic minerals, and combinations of one or more of these raw materials.

[0202] Metal oxides can for example be selected from silicon oxide, aluminium oxide, magnesium oxide, calcium oxide, barium oxide, lithium oxide, sodium oxide, potassium oxide, iron oxide, titanium oxide, manganese oxide, zinc oxide, and metal oxides that can be characterized as pigments such as cobalt oxide, chromium oxide, or iron oxide, and combinations thereof.

[0203] Non-metal oxides can for example be selected from boron oxide or phosphorous oxide and combinations thereof.

[0204] Suitable examples for non-metal compounds include boric acid.

[0205] Silicates can for example be selected from aluminum silicates, borosilicates, calcium silicates, magnesium silicates, sodium silicates, magnesium silicates, lithium silicates, and combinations thereof.

[0206] Minerals can for example be selected from clay, feldspar, kaolin, wollastonite, borax, quartz, soda ash, limestone, dolomite, chalk, and combinations thereof.

[0207] In the present invention, the vitreous bond phase may also be formed from a frit, i.e. a composition that has been pre-fired prior to its employment in a vitreous bond precursor composition for forming the vitreous bond phase of a bonded abrasive article. As used herein, the term "frit" is a generic term for a material that is formed by thoroughly blending a mixture comprising one or more frit forming components, followed by heating (also referred to as pre-firing) the mixture to a temperature at least high enough to melt it; cooling the glass and pulverizing it. The frit forming components are usually mixed together as powders, fired to fuse the mixture and then the fused mixture is cooled. The cooled mixture is crushed and screened to a fine powder to then be used as a frit bond. It is this final powder that may be used in a vitreous bond precursor composition to prepare the vitreous bond of a bonded abrasive article of the invention, such as a grinding wheel.

[0208] Frits, their sources and compositions are well known in the art. Frit forming components include materials which have been previously referred to as raw materials for forming a vitreous bond. Frits are well known materials and have been used for many years as enamels for coating, for example, porcelain, metals and jewelry, but also for vitreous bonds of technical ceramics and grinding wheels. Frits as well as ceramic bonds for vitrified bonded abrasive articles are commercially available from suppliers such as Ferro Corporation, 1000 Lakeside Avenue Cleveland, Ohio, USA 44114-7000 and Reimbold & Strick, Cologne, Germany. Frits for the use in vitrified bonded abrasive articles typically show melting temperatures in the range of 500 to 1300°C.

[0209] In accordance with the present invention, frits may be used in addition to the raw materials or in lieu of the raw materials. Alternatively, the vitreous bond may be derived from a non-frit containing composition.

[0210] For example, a vitreous bond can be formed from a vitreous bond precursor composition comprising from more than 0 to 100% by weight frit, although more typically the composition comprises 3 to 70% frit. The remaining portion of the vitreous bond precursor composition can be a non-frit material.

[0211] Suitable ranges for vitrified bond compositions can be specified as follows: 25 to 90% by weight, preferably 35 to 85% by weight, based on the total weight of the vitreous bond, of SiO_2 ; 0 to 40% by weight, preferably 0 to 30% by weight, based on the total weight of the vitreous bond, of B_2O_3 ; 0 to 40% by weight, preferably 5 to 30% by weight, based on the total weight of the vitreous bond, of Al_2O_3 ; 0 to 5% by weight, preferably 0 to 3% by weight, based on the total weight of the vitreous bond, of Fe_2O_3 ; 0 to 5% by weight, preferably 0 to 3% by weight, based on the total weight of the vitreous bond, of TiO_2 ; 0 to 20% by weight, preferably 0 to 10% by weight, based on the total weight of the vitreous bond, of CaO ; 0 to 20% by weight, preferably 0 to 10% by weight, based on the total weight of the vitreous bond, of MgO ; 0 to 20% by weight, preferably 0 to 15% by weight, based on the total weight of the vitreous bond, of K_2O ; 0 to 25% by weight, preferably 0 to 15% by weight, based on the total weight of the vitreous bond, of Na_2O ; 0 to 20% by weight, preferably 0 to 12% by weight, based on the total weight of the vitreous bond, of Li_2O ; 0 to 10% by weight, preferably 0 to 3% by weight, based on the total weight of the vitreous bond, of ZnO ; 0 to 10% by weight, preferably 0 to 3% by weight, based on the total weight of the vitreous bond, of BaO ; and 0 to 5% by weight, preferably 0 to 3% by weight, based on the total weight of the vitreous bond, of metallic oxides [e.g. CoO , Cr_2O_3 (pigments)].

[0212] It is known in the art to use various additives in the making of vitreous bonded abrasive articles both to assist in the making of the abrasive article and/or improve the performance of such articles. Such conventional additives which

may also be used in the practice of this invention include but are not limited to lubricants, fillers, temporary binders and processing aids.

[0213] Organic binders are preferably used as temporary binders. Typical temporary binders are dextrans, urea resins (including urea formaldehyde resins), polysaccharides, polyethylene glycol, polyacrylates, and any other types of glue etc. These binders may also include a liquid component, such as water or polyethylene glycol, viscosity or pH modifiers and mixing aids. The use of temporary binders may improve homogeneity and the structural quality of the pre-fired or green pressed body as well as of the fired article. Because the binders are burned out during firing, they do not become part of the finished bond or abrasive article.

[0214] Bonded abrasive articles according to the present invention can be made according to any suitable method. Procedures and conditions well known in the art for producing vitrified bonded abrasive articles (e.g., grinding wheels) and especially procedures and conditions for producing vitreous bonded sol-gel alumina-based abrasive articles may be used to make the abrasive article of this invention. These procedures may employ conventional and well known equipment in the art.

[0215] During manufacture of a vitrified bonded abrasive article, the vitreous bond precursor composition, in a powder form, may be mixed with a temporary binder (typically an organic binder) which does not form part of the fired vitrified bonding medium. Bonded abrasive articles are typically prepared by forming a green structure comprised of abrasive grain, the vitreous bond precursor composition, and optionally, a temporary binder and other optional additives and fillers. Forming can for example be accomplished by molding with or without pressing. Typical forming pressures can vary within wide ranges and may be selected from pressures ranging from 0 to 400 kg/cm², depending on the composition of the green structure. The green structure is then fired. The vitreous bond phase is usually produced in the firing step, typically at a temperature(s) in the range from about 700 °C to about 1500 °C, preferably in the range from about 750°C to about 1350°C and most preferably in the range from about 800°C to about 1300°C. The actual temperature at which the vitreous bond phase is formed depends, for example, on the particular bond chemistry. Firing of the vitreous bond precursor composition is typically accomplished by raising the temperature from room temperature to the maximum temperature over a prolonged period of time (e.g., about 10-130 hours), holding at the maximum temperature, e.g., for 1-20 hours, and then cooling the fired article to room temperature over an extended period of time, e.g., 10-140 hours. It should be understood that the temperature selected for the firing step and the composition of the vitreous bond phase must be chosen so as to not have a detrimental effect on the physical properties and/or composition of the abrasive particles (shaped and optional secondary particles) contained in the abrasive article.

[0216] A bonded abrasive article according to the present invention comprises shaped abrasive particles (as defined in accordance with the present invention) and a bonding medium comprising a vitreous bond. In addition, the bonded abrasive article may comprise one or more optional components selected from secondary abrasive particles, fillers and additives.

[0217] As used herein the term "secondary abrasive particles" is intended to generally refer to abrasive particles which differ from the shaped abrasive particles to be used in accordance with the present invention.

[0218] The amounts of abrasive particles (which may be comprised in a blend including one or more secondary abrasive particles) may vary widely and can range for example from 10 to 80 %, more preferably from 25 to 60 % by volume. While the invention has a most pronounced effect wherein the blend includes 100% by weight of shaped abrasive particles in accordance with the present invention, it is also effective when the article contains for example as little as 5% by weight of shaped abrasive particles in accordance with the present invention and up to 95% by weight of secondary abrasive particles. Hence, the abrasive articles can contain up to 100% by weight of the abrasive particles according to this invention. In some embodiments, the bonded abrasive article can include from about 5 to 100, preferably 10 to 80 percent by weight of shaped abrasive particles; typically 20 to 60 percent by weight, and more typically 30 to 50 percent by weight, based on the total weight of the bonding medium and abrasive particles. In some grinding applications the addition of a secondary abrasive particle is for the purpose of reducing the cost of the abrasive article by reducing the amount of premium priced shaped abrasive particles. In other applications a mixture with a secondary abrasive particle may have a synergistic effect.

[0219] The amount of bonding medium may also vary widely and can range for example from 1 to 60 % by volume, more preferably 2.5 to 40% by volume.

[0220] Optionally, the bonded abrasive article can comprise porosity. Bonded abrasive articles containing porosity have an open structure (interlinked or interconnected porosity) which can provide chip clearance for high material removal, transport more coolant into the contact area while decreasing friction, and optimizes the self-sharpening process. Porosity enables the bonded abrasive article to shed used or worn abrasive particles to expose new cutting edges or fresh abrasive particles.

[0221] Bonded abrasive articles according to the present invention can have any useful range of porosity; such as from about 5 to about 80 % by volume, preferably from about 20 to about 70 % by volume.

[0222] Preferably, the bonded abrasive article according to the present invention contains porosity. The porosity can be formed by the natural spacing provided by the packing density of the materials comprised in the bonded abrasive

articles and by pore inducing components, as known in the art, or by both.

[0223] Pore inducing components can be selected from temporary components (i.e. components not present in the final article) non-temporary components (i.e. (components present in the final article) and combinations thereof. Preferred pore inducing components should not leave any chemical traces in a finished abrasive article (i.e. be temporary components), do not expand upon removal mix well with the abrasive particles and can provide the desired type (e.g. interconnected) and extent of porosity. Pore inducing components are typically used in amounts ranging from 0-40 Vol.-% of the total article. Typical pore non-temporary pore inducing components may be selected from materials such as hollow spheres made of materials such as glass, ceramic (aluminium oxide) and glass particles. Typical temporary pore-inducing components may be selected from materials such as polymeric materials (including foamed polymeric materials) cork, ground walnut shells, wood particles organic compounds (such as naphthalene or paradichlorbenzene) and combinations thereof. In a preferred embodiment, the abrasive article contains porosity induced by using naphthalene (as a temporary pore inducing component).

[0224] As discussed, the shaped abrasive particles to be used in the present invention can be comprised in a plurality of abrasive particles. A plurality can comprise shaped abrasive particles in accordance with the present invention and other abrasive particles which are not in accordance with the present invention (such other abrasive particles are also referred to herein as secondary abrasive particles). For example, abrasive particles having a shape not in accordance with the present invention (for example filamentary abrasive particles or elongated rods) or conventional non-shaped abrasive particles could be used as secondary abrasive particles.

[0225] The secondary abrasive particles may have any suitable particle form (as long as it is different from the shape of the abrasive particle for use in the invention). Suitable particle forms include particle forms obtained by mechanical crushing operation, agglomerated forms and any other forms that differ from the specific abrasive particle shapes as defined herein.

[0226] For example, the abrasive article may further comprise crushed abrasive particles (excluding abrasive shards as defined herein) which can optionally correspond to an abrasive industry specified nominal graded or combination thereof). The crushed abrasive particles can be of a finer size grade or grades (e.g., if a plurality of size grades are used) than the shaped abrasive particles. In some embodiments, the crushed abrasive particles can be of a coarser size grade or grades (e.g., if a plurality of size grades are used) than the shaped abrasive particles,

Representative examples of materials of secondary abrasive particles include for example particles of fused aluminum oxide, e.g., white fused alumina, heat treated aluminum oxide, ceramic aluminum oxide materials such as those commercially available under the trade designation 3M CERAMIC ABRASIVE GRAIN from 3M Company of St. Paul, Minnesota, sintered aluminum oxide, silicon carbide (including black silicon carbide and green silicon carbide), titanium diboride, boron carbide, tungsten carbide, titanium carbide, diamond, cubic boron nitride, garnet, fused alumina-zirconia, sol-gel derived abrasive particles (including sol-gel-derived aluminum oxide particles), cerium oxide, zirconium oxide, titanium oxide. Examples of sol-gel derived abrasive particles can be found in U.S. Patent Nos. 4,314,827 (Leitheiser et al.), 4,623,364 (Cottringer et al.); 4,744,802 (Schwabel), 4,770,671 (Monroe et al.); and 4,881,951 (Monroe et al.).

[0227] Typically, conventional crushed abrasive particles are independently sized according to an abrasives industry recognized specified nominal grade. Exemplary abrasive industry recognized grading standards and grades for secondary abrasive particles include those as mentioned with respect to shaped abrasive particles.

[0228] Bonded abrasive articles according to the present invention may contain additional components such as, for example, fillers and additives, as is known in the art. Examples of optional additives contained in the bonded abrasive article include non-temporary pore inducing agents, as described in the foregoing and any components used when making the vitreous bond, including but not limited to lubricants, fillers, temporary binders and processing aids.

[0229] Bonded abrasive articles in accordance with the present invention have a three dimensional shape, which is not particularly limited. Suitable shapes can for example include the shape of a wheel, honing stone, grinding segment, mounted point or other types and as to shapes of FEPA or ISO 603:1999 and other standards as well as non-standard individual types. A preferred bonded abrasive article is a vitrified bonded abrasive wheel, in particular, a vitrified bonded grinding wheel.

[0230] The diameter of abrasive wheels in accordance with the present invention is not particularly limited and can for example be selected to range from 1 mm to 2000 mm, or from 10 mm to 1200 mm or from 100 mm to 750 mm, although other dimensions may also be used. Likewise, the thickness of grinding wheels in accordance is not particularly limited. For example, the thickness can typically be selected to range from 2 to 600 mm, or from 5 to 350 mm, or from 10 mm to 300 mm, although other dimensions may also be used. For example, a bore diameter may range from 0 mm to 800 mm, more typically from 4 mm to 400 or from 8 mm to 350 mm.

[0231] The particular design of the abrasive article (preferably grinding wheel) is not limited and can be selected from "monolithic" designs and "zonal" design (such as segmented and layered designs). Both designs can include the reinforcement of the bore by using glues such as thermosetting resins, for example resins selected from epoxy resins, polycondensates, and phenolic resins.

[0232] The abrasive particles (i.e. one or more type of shaped abrasive particles and optionally one or more types of

secondary abrasive particles) may be homogeneously or non-homogeneously distributed in the abrasive article, for example be distributed or concentrated in selected areas, layers segments or portions of the abrasive article. Homogeneous or non-homogeneous distribution may be either as a homogeneous blend or in a way that different types of abrasive particles are located and distributed only in selected areas, layers, segments or portions of the abrasive article.

[0233] For example, a bonded abrasive wheel, may comprise at least two distinct sections, including an outer zone (also often referred to as rim or periphery) and an inner zone (also often referred to as core or center portion). The distinct sections may be provided based on differences in one or more aspects selected from the composition of the bond (for example the type of bonding material or the amount of porosity present), the shape of abrasive particles (for example shaped versus crushed or first shape versus second shape), the grit size of abrasive particle (for example, finer versus coarser) and the amount of abrasive particles (for example presence or absence of abrasive particles or first (for example high) amount versus second (for example low) amount).

[0234] In some embodiments the outer zone comprises shaped abrasive particles according to the present invention whereas the inner zone does not.

[0235] In other embodiments, the inner zone comprises shaped abrasive particles according to the present invention whereas the outer zone does not.

[0236] An abrasive wheel may also contain an inner zone made of a non-vitreous bonding material (such as plastics etc.).

[0237] If the bonded abrasive article is an abrasive wheel, such as a grinding wheel, the abrasive particles may be concentrated towards the middle, or only in the outer zone, i.e., the periphery, of the wheel. The center portion may contain a different (higher or lower) amount of abrasive particles.

[0238] Another example for a zonal design is an abrasive wheel, such as a grinding wheel, having a rim containing shaped abrasive particles in accordance with the present invention and an inner zone optionally containing and preferably not containing shaped abrasive particles in accordance with the present invention. The inner zone of this design may optionally contain secondary abrasive particles (e.g. fused alumina, sintered alumina) that may have the same or different grit size. This design is also referred to as special centre design which is intended to minimize the grinding wheel costs due to the lack of shaped abrasive particles and at the same time to increase the bursting speed.

[0239] In another variation, an abrasive wheel may include two or more types of abrasive particles positioned on different sides of the abrasive wheel. For example, first abrasive particles may be on one side of the wheel with different abrasive particles on the opposite side. Either the first or the second abrasive particles or both are selected from shaped abrasive particles in accordance with the present invention. However, typically all the abrasive particles are homogeneously distributed among each other, because the manufacture of the wheels is easier, and the grinding effect is optimized when the abrasive particles or the two or more types thereof are closely positioned to each other.

[0240] In one embodiment, abrasive particles according to the present invention are homogeneously distributed throughout the bonded abrasive article.

[0241] The bonded abrasive articles of this invention are particularly suitable for applications including cylindrical grinding (outer diameter or OD grinding as well as inner diameter or ID grinding), centerless grinding, surface and profile grinding, reciprocating grinding, creep-feed grinding, grinding in generating method of gears, threads, tools, camshafts, crankshafts, bearings, guard rails, etc. Cut-off operations are less preferred but included within the scope of the present invention. Particularly preferred applications include creep-feed grinding, surface grinding, profile grinding, reciprocating grinding, grinding in generating method, cylindrical grinding (OD and ID grinding) and centerless grinding.

[0242] The applied force during abrading is not particularly limited and can be selected on the basis of the grinding application.

[0243] During use, the bonded abrasive article can be used dry or wet. During wet grinding, the bonded abrasive article is used in conjunction with water or commercially available lubricants (also referred to as coolants). Lubricants are sometimes used to cool the workpiece and wheel, lubricate the interface, and remove swarf (chips). The lubricant is typically applied directly to the grinding area to ensure that the fluid is not carried away by the grinding wheel. The type of lubrication used depends on the workpiece material and can be selected as is known in the art.

[0244] Common lubricants can be classified based on their ability to mix with water. A first class suitable for use in the present invention includes oils, such as mineral oils (typically petroleum based oils) and plant oils. A second class suitably for use in the present invention includes emulsions of lubricants (for example mineral oil based lubricants; plant oil based lubricants and semi-synthetic lubricants) and solutions of lubricants (typically semi-synthetic and synthetic lubricants) with water.

[0245] Abrasive articles in accordance with the present invention can be used on any grinding machine specific for the grinding method. The grinding machine can be electrically, hydraulically or pneumatically driven, at any suitable speed, generally at speeds from about 10 to 250 m/s.

[0246] Bonded abrasive articles according to the present invention are useful, for example, for abrading a workpiece. The bonded abrasive article can be particularly suitable for use on workpieces made of metal, such as steel (including powder metallurgical steel and steel alloys, carbon steels, mild steels, tool steels, stainless steel, hardened steel, ball

bearing steel, cold working steel, cast iron), non-ferrous metals and alloys (such as aluminum, titanium, bronze, etc.) hard metals (such as tungsten carbide, titanium carbide, titanium nitride, cermets, etc), ceramics (technical ceramics such as oxide ceramics, silicate ceramics, non-oxide ceramics), and glasses. The use of the bonded abrasive articles is however not restricted to the use on these exemplified workpieces.

[0247] Bonded abrasive articles of the present invention can be advantageously used in many grinding applications, in particular grinding applications selected from roughing and semi-roughing operations typically involving high material removal rates. Finishing operations typically do not include such high material removal rates and therefore do not represent preferred grinding applications of bonded abrasive articles of the invention.

[0248] Surprisingly, bonded abrasive articles in accordance with the present invention have been found to provide excellent results in high performance grinding applications.

[0249] For the purposes of the present invention, the term high performance grinding application is intended to refer to higher material removal rates than is commonly possible with present day conventional abrasives. Conventional abrasives encompass all types of aluminium oxide including so-called ceramic abrasives, and silicon carbide.

[0250] High performance grinding can be established for a specific grinding application based on the knowledge of sound grinding engineering and adequate modern CNC (Computerized Numerical Control) machinery. One parameter to define high performance grinding could be the specific material removal rate Q'_w also called Q-prime. Q'_w indicates how many mm³ of workpiece material one mm wheel width removes per second (mm³/mm/sec). Q'_w can be calculated based on two parameters, namely the depth of cut a_e and the feed rate v_w , according to the formula $Q'_w = [a_e \times v_w]/60$. The specific material removal rate Q'_w can be increased by increasing the feed rate v_w and/or the depth of cut a_e . [The peripheral speed v_c does not have an influence on Q'_w .]

[0251] Typical ranges for Q'_w for exemplary high performance grinding applications can be specified as follows: Inner diameter (ID-) grinding 1-15, preferably 2-12, most preferably 4-11 mm³/mm/s; outer diameter (OD-) grinding 1.5-25, preferably 3-22, most preferably 4-20 mm³/mm/s; surface grinding 1.5-20, preferably 2-17, most preferably 4-19 mm³/mm/s; profile grinding 3-50, preferably 5-45, most preferably 7-40 mm³/mm/s; profile grinding with generating method 8-60, preferably 10-55, most preferably 14-50 mm³/mm/s; creep-feed grinding 4-100, preferably 6-90, most preferably 9-80 mm³/mm/s; and camshaft grinding 8-100, preferably 12-95, most preferably 15-90 mm³/mm/s.

[0252] While the values mentioned above refer to roughing and semi-roughing operations, in finishing operations the Q'_w values may be <1 mm³/mm/s.

[0253] In addition, bonded abrasive articles in accordance with the present invention can provide a better surface finish (decreased surface roughness Ra) on the workpiece used.

[0254] The effects achieved in the present invention are also unexpected in view of the fact that the bonded abrasive article typically does not have to comprise the shaped abrasive in any specific orientation. Unlike the situation in comparatively thin coated abrasive articles where orientation may be of advantage, the bonded abrasive article (for example, wheel, segment, layer or part thereof) typically comprises the shaped abrasive particles in a random orientation, although orientation of the particles is not excluded from the scope of the present invention.

[0255] The present invention also relates to a method for abrading a workpiece, the method comprising frictionally contacting at least a portion of an abrasive article in accordance with the invention with a surface of a workpiece; and moving (for example rotating) at least one of the workpiece or the abrasive article to abrade at least a portion of the surface of the workpiece.

[0256] In embodiments, the present invention relates to the following items:

1. A bonded abrasive article as defined in claim 1.
2. The article of item 1, wherein the thickness t is smaller than the length of the shortest side-related dimension of the particle.
3. The article according to items 1 or 2, wherein the shaped abrasive particles are ceramic shaped abrasive particles.
4. The article according to any of items 1 to 3, wherein the shaped abrasive particles comprise alpha alumina.
5. The article according to any of items 1 to 4, wherein the shaped abrasive particles comprise non seeded sol-gel derived alpha alumina.
6. The article according to any of items 1 to 4, wherein the shaped abrasive particles comprise seeded sol-gel derived alpha alumina.
7. The article according to any of items 1 to 6, further comprising secondary abrasive particles.

8. The article according to item 7, wherein the shaped and secondary abrasive particles are independently selected from particles of fused aluminum oxide materials, heat treated aluminum oxide materials, ceramic aluminum oxide materials, sintered aluminum oxide materials, silicon carbide materials, titanium diboride, boron carbide, tungsten carbide, titanium carbide, diamond, cubic boron nitride, garnet, fused alumina-zirconia, sol-gel derived abrasive particles, cerium oxide, zirconium oxide, titanium oxide or a combination thereof.

9. The article according to item 7 or 8 wherein the secondary abrasive particles are selected from crushed abrasive particles having a specified nominal grade.

10. The article according to item 9, wherein the crushed abrasive particles are of a smaller size than the shaped abrasive particles.

11. The article according to any of items 1 to 10 comprising 10 to 80 % by volume of said shaped abrasive particles.

12. The article according to any of items 1 to 11 comprising 1 to 60 % by volume of said bonding medium.

13. The article according to any of items 1 to 12, wherein said vitreous bond comprises, based on the total weight of the vitreous bond, 25 to 90% by weight of SiO_2 ; 0 to 40% by weight of B_2O_3 ; 0 to 40% by weight of Al_2O_3 ; 0 to 5% by weight of Fe_2O_3 ; 0 to 5% by weight of TiO_2 ; 0 to 20% by weight of CaO ; 0 to 20% by weight of MgO ; 0 to 20% by weight of K_2O ; 0 to 25% by weight of Na_2O ; 0 to 20% by weight of Li_2O ; 0 to 10% by weight of ZnO ; 0 to 10% by weight of BaO ; and 0 to 5% by weight of metallic oxides.

14. The article according to any of items 1 to 13, wherein the vitreous bond is obtainable from a vitreous bond precursor composition comprising frit.

15. The article according to item 14, wherein the vitreous bond precursor composition comprises 3 to 70 % by weight of a frit based on the total weight of the vitreous bond precursor composition.

16. The article according to any of items 1 to 15, comprising porosity.

17. The article according to any of items 1 to 16 comprising, based on the volume of the article 1 to 60 % by volume of a vitreous bond, 10 to 80 % by volume of shaped abrasive particles and 5 to 80 % by volume of porosity.

18. The article according to any of items 7 to 17 wherein the shaped abrasive particles and the secondary abrasive particles are comprised in a blend, wherein the content of the secondary abrasive particles is up to 95% by weight based on the total weight of abrasive particles present in the blend.

19. The article according to any of items 1 to 18, wherein the ratio of the length of the shortest side-related dimension to the thickness of said particle is at least 1:1.

20. The article according to any of items 1 to 19, wherein said first geometric shape is selected from polygonal shapes.

21. The article according to any of items 1 to 20 wherein said first geometric shape is selected from triangular shapes and quadrilateral shapes.

22. The article according to any of items 1 to 21 wherein said first geometric shape is a quadrilateral shape selected from a rectangle, a rhombus, a rhomboid, a kite, or a superellipse.

23. The article according to any of items 1 to 22 wherein said first geometric shape is a triangular shape selected from isosceles triangular shapes and equilateral triangular shapes.

24. The article according to any of items 1 to 23, wherein the shaped abrasive particles have a volumetric aspect ratio and the volumetric aspect ratio is greater than about 1.15.

25. The article according to any of items 1 to 24, comprising at least one sidewall.

26. The article according to item 25, wherein the sidewall comprises one or more facets.

27. The article according to item 26, wherein the one or more facets have a shape independently selected from triangular and quadrilateral geometric shapes and combinations thereof.

28. The article according to item any of items 25 to 27, wherein the at least one sidewall is a sloping sidewall.

29. The article according to any of items 25 to 28, further comprising a draft angle α between the second face and the sidewall, the draft angle α being greater than 90 degrees.

30. The article of item 29, wherein the draft angle α is between about 95 to about 135 degrees.

31. The article according to any of items 25 to 28, wherein the sidewall intersects the first side at an angle β of between 5 to about 65 degrees.

32. The article according to any of items 1 to 31, wherein said shaped abrasive particles each comprise at least one shape feature selected from: an opening, at least one recessed (or concave) face; at least one face which is shaped outwardly (or convex); at least one side having a plurality of grooves or ridges; a low roundness factor; a perimeter of the first face comprising one or more corner points having a sharp tip; a second side comprising a second face having a perimeter comprising one or more corner points having a sharp tip; or a combination of one or more of said shape features.

33. The article according to any of items 1 to 32, wherein the shaped abrasive particles each have an opening.

34. The article according to any of item 33, wherein the opening passes through the first side and the second side.

35. The article according to any of items 1 to 34, wherein the shaped abrasive particles further comprise a plurality of grooves and/or ridges on the second side.

36. The article according to any of items 1 to 35 wherein the second side comprises a vertex or a ridge line or a second face.

37. The article according to item 36, wherein the second side comprises a second face separated from the first side by thickness t and at least one sidewall connecting the second face and the first face.

38. The article according to item 37, wherein the thickness is equal to or smaller than the length of the shortest facial dimension of the particle.

39. The article according to item 37 or 38, wherein the second face has a perimeter of a second geometric shape which may be the same or different to the first geometric shape.

40. The article according to item 39 wherein said first and second geometric shapes are independently selected from regular polygons and irregular polygons.

41. The article according to items 39 or 40 wherein the first and second geometric shapes have identical geometric shapes which may or may not be different in size.

42. The article according to item 41, wherein the first and second geometric shapes are selected from substantially triangular shapes.

43. The article according to item 42, wherein the substantially triangular shape comprise the shape of an equilateral triangle.

44. The article according to any of items 37 to 43, wherein the first face and the second face are substantially parallel to each other.

45. The article according to any of items 37 to 44, wherein the first face and the second face are nonparallel to each other.

46. The article according to any of items 37 to 45, wherein the sidewall is a sloping sidewall.

47. The article according to any of items 37 to 46, further comprising a draft angle α between the second face and the sidewall, and the draft angle α is greater than 90 degrees.

48. The articles according to item any of items 37 to 47 comprising a first sloping sidewall having a first draft angle, a second sloping sidewall having a second draft angle, and a third sloping sidewall having a third draft angle.

49. The article according to item 48, wherein the first draft angle, and the second draft angle, and the third draft angle are different values from each other.

50. The article according to item 48, wherein the first draft angle, the second draft angle, and the third draft angle are equal.

51. The article according to any of items 37 to 50, wherein the first and the second face are substantially planar.

52. The article according to any of items 37 to 50, wherein at least one of the first and second face is a non-planar face.

53. The article according to item 52, wherein the first face is recessed or concave and the second face is substantially planar.

54. The articles according to item 52, wherein the first face is convex and the second face is recessed or concave.

55. The article according to item 52, wherein the first face is recessed or concave and the second face is recessed or concave.

56. The article according to item 52, wherein the particles are dish-shaped abrasive particles each having a sidewall and a varying thickness t , wherein the first face is recessed and a thickness ratio of T_c/T_i for the dish-shaped abrasive particles is between 1.25 to 5.00.

57. The article according to item 52 or 56, wherein the first face comprises a substantially planar center portion and a plurality of raised corners.

58. The article according to any of items 37 to 57, wherein the second side comprises a second face and four facets intersecting the second face at a draft angle α forming a truncated pyramid.

59. The article of item 58, wherein the draft angle α is between about 95 to about 135 degrees.

60. The article according to item 36, wherein the second side comprises a vertex separated from the first side by thickness t and at least one sidewall connecting the vertex and the perimeter of the first face.

61. The article according to item 60, wherein the sidewall comprises one or more facets connecting the vertex and the perimeter of the first face.

62. The article according to item 60 or 61, wherein the perimeter of the first face is trilateral, quadrilateral or higher polygonal and wherein the second side comprises a vertex and the corresponding number of facets for forming a pyramid.

63. The article according to any of items 60 to 62, wherein the first side comprises a quadrilateral having four edges and four vertices with the quadrilateral being selected from the group consisting of a rectangle, rhombus, a rhomboid, a kite, or a superellipse.

64. The article according to any of items 60 to 62, wherein the first side comprises a trilateral having three edges and three vertices and the second side comprise a vertex and three triangular facets forming a pyramid.

65. The article according to item 64, wherein the trilateral is an equilateral triangle.

66. The article according to any of items item 60 to 65, wherein the sidewall and/or or facets intersect the first side at an angle β of between about 5 to about 65 degrees.

EP 2 567 784 B1

67. The article according to item 64, wherein the shaped abrasive particles have four major sides joined by six common edges, wherein each one of the four major sides contacts three other of the four major sides, and wherein the six common edges have substantially the same length.

5 68. The article according to item 67, wherein at least one of the four major sides is substantially planar.

69. The article according to item 67 or 68, wherein at least one of the four major sides is concave.

10 70. The article according to item 67, wherein all of the four major sides are concave.

71. The article according to item 67 or 68, wherein at least one of the four major sides is convex.

72. The article according to any of items 67 to 71, wherein the shaped abrasive particles have tetrahedral symmetry.

15 73. The article according to any of items 67 to 72, wherein the shaped particles are substantially shaped as regular tetrahedrons.

20 74. The article according to item 36, wherein the second side comprises a ridge line separated from the first side by thickness t and at least one sidewall connecting the ridge line and the perimeter of the first face.

75. The article according to item 74, wherein the sidewall comprises one or more facets connecting the ridge line and the perimeter of the first face.

25 76. The article according to any of item 74 or 75 wherein the sidewall and/or facets intersect the first side at an angle β of between about 5 to about 65 degrees.

77. The article according to any of items 74 to 76, wherein the first geometric shape is selected from quadrilateral geometric shapes and the sidewall comprises four facets forming a roof-shaped particle.

30 78. The article according to item 77 wherein the quadrilateral shape is selected from the group consisting of a rectangle, a rhombus, a rhomboid, a kite, or a superellipse.

35 79. The articles according to any of items 1 to 78, wherein the abrasive particles have an average tip radius and the average tip radius is less than 75 microns.

40 80. The article according to any of items 1 to 79, wherein the shaped abrasive particles each have a cross-sectional shape along a longitudinal axis of the shaped abrasive particles, the cross-sectional shape comprising a non-circular cross-sectional plane, and the shaped abrasive particles comprise an Average Roundness Factor of between about 15% to 0%.

81. The article according to any of items 1 to 80 having a three dimensional shape selected from the shape of a wheel, honing stone, grinding segment, mounted points or other shapes.

45 82. The article according to any of items 1 to 81, wherein the article comprises a wheel.

83. The article according to any of items 1 to 82, wherein the article is a wheel.

50 84. The article according to any of items 82 or 83, wherein the wheel is selected from grinding wheels for cylindrical grinding, centerless grinding, surface and profile grinding, reciprocating grinding, creep-feed grinding, grinding in generating methods of gears, threads, tools, camshafts, crankshafts bearings, and guard rails.

85. The article according to any of items 1 to 84, wherein the shaped abrasive particles are homogeneously distributed in the abrasive article.

55 86. The article according to any of items 1 to 84, wherein the shaped abrasive particles are non-homogeneously distributed in the abrasive article.

87. The article according to item 86, which is or comprises a bonded abrasive wheel, the wheel comprising an outer

zone and an inner zone, wherein the compositions of the inner and outer zone differ in one or more aspects selected from the composition of the bond, the shape of abrasive particles, the grit size of abrasive particle, and the amount of abrasive particles.

88. Use of an article according to any of items 1 to 87 in high performance grinding applications.

89. Use according to claim 88 for outer diameter grinding with a Q'_w of at least 1.5 mm³/mm/sec, inner diameter grinding with a Q'_w of at least 1 mm³/mm/sec, surface grinding with a Q'_w of at least 1.5 mm³/mm/sec, profile grinding with a Q'_w of at least 3 mm³/mm/sec, profile grinding with generating method with a Q'_w of at least 8 mm³/mm/sec, creep-feed grinding with a Q'_w of at least 4 mm³/mm/sec, and camshaft grinding with a Q'_w of at least 8 mm³/mm/sec.

90. Use of an article according to any of claims 1 to 87 for abrading a workpiece material selected from steels, non-ferrous metals, alloys, hard metals, ceramics and glasses.

91. Method for abrading a workpiece, the method comprising frictionally contacting at least a portion of the abrasive article according to any of items 1 to 87 with a surface of a workpiece; and moving at least one of the workpiece or the abrasive article to abrade at least a portion of the surface of the workpiece.

[0257] Objectives and advantages of this disclosure are further illustrated by the following non-limiting examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this disclosure.

EXAMPLES

[0258] Unless otherwise noted, all parts, percentages, ratios, etc. in the Examples and the rest of the specification are by weight.

A. Materials used in the Examples

[0259]

80+	Shaped abrasive particles with the composition of 3M TM Ceramic Abrasive Grain 321 with each abrasive particle shaped as a triangular prism with sloping side walls
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	(side wall draft angle 98 degrees) with two substantially parallel faces, wherein the first face comprises an equilateral triangle with a median dimension of 0.49mm and the second face also comprises an equilateral triangle of median edge length of 0.415mm. The average distance between the faces was 0.095mm.										
60+	Shaped abrasive particles with the composition of 3M TM Ceramic Abrasive Grain 321 with each abrasive particle shaped as a triangular prism with sloping side walls (side wall draft angle 98 degrees) with two substantially parallel faces, wherein the first face comprises an equilateral triangle with a median dimension of 0.63mm and the second face also comprises an equilateral triangle of median edge length of 0.540mm. The average distance between the faces was 0.120mm										
T	Shaped abrasive particles with the composition of 3M TM Ceramic Abrasive Grain 321 with each abrasive particle shaped as a tetrahedron with a median edge length of 0.510mm										
white fused aluminium oxide	available as Alodur® WSK from Treibacher Schleifmittel AG, Austria in grit size F70, F80, and F100 according to FEPA-Standard 44-1:2006										
3M TM Ceramic Abrasive Grain 321 ANSI grit 80.	crushed non seeded sol gel derived crushed ceramic alpha alumina based abrasive particles having the same chemical composition: <table border="1" data-bbox="614 1668 1380 1870"> <tr> <td>Al₂O₃</td><td>94 – 96%</td></tr> <tr> <td>MgO</td><td>1.2% +/- 0.3%</td></tr> <tr> <td>Y₂O₃</td><td>1.2% +/- 0.3%</td></tr> <tr> <td>La₂O₃ + Nd₂O₃</td><td>2.4% +/- 0.5%</td></tr> <tr> <td colspan="2">Traces of : TiO₂, SiO₂, CaO, and CoO and Fe</td></tr> </table> and having grit size ANSI 80 and ANSI 90, available	Al ₂ O ₃	94 – 96%	MgO	1.2% +/- 0.3%	Y ₂ O ₃	1.2% +/- 0.3%	La ₂ O ₃ + Nd ₂ O ₃	2.4% +/- 0.5%	Traces of : TiO ₂ , SiO ₂ , CaO, and CoO and Fe	
Al ₂ O ₃	94 – 96%										
MgO	1.2% +/- 0.3%										
Y ₂ O ₃	1.2% +/- 0.3%										
La ₂ O ₃ + Nd ₂ O ₃	2.4% +/- 0.5%										
Traces of : TiO ₂ , SiO ₂ , CaO, and CoO and Fe											

	from 3M Innovative Properties, USA
5 10 15	Cerpass TGE®, Code TGE-0557, grit size 100 Extruded abrasive rods composed of seeded gel product; containing $\geq 99.6\%$ alpha aluminium oxide in grit size 100 with an aspect ratio [the ratio of the length to the greatest cross-sectional dimension, (the greatest dimension perpendicular to the length)] in the range of 3.3-5.1 and a side dimension of the cross-sectional area of 140-152 μm, Saint-Gobain Grains & Powders, Worcester, USA
20 25	Mix 1 – Comparative Example Ref. 1A-2 100% by weight white fused aluminium oxide based on the total weight of abrasive grain, consisting of 20% by weight of FEPA grade F70, 50% by weight of FEPA grade F80, and 30% by weight of FEPA grade F100
30 35 40	Mix 2 – Comparative Example Ref. 2A-1 30% by weight 3M™ Ceramic Abrasive Grain 321 and 70% by weight of white fused aluminum oxide based on the total weight of abrasive grain The 3M™ Ceramic Abrasive Grain 321 portion consists of each 50% by weight of ANSI grade 80 and ANSI grade 90. The portion of white fused aluminium oxide consists of each 28.6% by weight of FEPA grade F70 and F100, and 42.8% by weight of FEPA grade F80.
45 50 55	Mix 3 – Examples 1A-1, and 1B-1 30% by weight 80+ and 70% by weight white fused alumina by weight based on the total weight of abrasive grain The portion of white fused aluminium oxide consists of each 28.6% by weight of FEPA grade F70 and F100, and 42.8% by weight of FEPA grade F80
	Mix 4 Examples 2A-1, 30% by weight 60+ and 70% by weight of white fused

and 2B-1	alumina based on the total weight of abrasive grain The portion of white fused aluminium oxide consists of each 28.6% by weight of FEPA grade F70 and F100, and 42.8% by weight of FEPA grade F80
Mix 5 Examples 3A-1, and 3B-1	30% by weight T and 70% by weight of white fused aluminium oxide based on the total weight of abrasive grain The portion of white fused aluminium oxide consists of each 28.6% by weight of FEPA grade F70 and F100, and 42.8% by weight of FEPA grade F80
Mix 6 Examples 1B-1, and 1B-2	100% by weight 80+ based on the total weight of abrasive grain
Mix 7 Comparative Example Ref. 3A-1)	30% by weight Cerpass TGE grit size 100 and 70% by weight of white fused aluminium oxide of Abrasive Grain Mix 7 based on the total weight of abrasive grain The portion of white fused aluminium oxide consists of each 28.6% by weight of FEPA grade F70
Mix 8 Comparative Example Ref. 3A-2	100% by weight Cerpass TGE® grit size 100 based on the total weight of abrasive grain
Vitrified bond precursor mix	Vitreous bond VO 82069 available from Reimbold & Strick, Germany
Temporary binder	Consisting of Liquid temporary binder mix and solid temporary binder
Liquid temporary binder mix	Urea formaldehyde resin PA1175G available from PA resins ab, Sweden

Solid temporary binder	Potato starch Dextrin 20.912 available from Agrana Stärke GmbH, Austria
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B. Manufacturing process of abrasive grinding wheels

[0260] Vitrified bonded abrasive grinding wheels having the same bond and wheel dimension of 500 x 25 x 304.8 mm (wheel diameter x thickness x bore diameter) were prepared according to the following manufacturing process.

(i) Mixing

[0261] The abrasive grain/grain mix as specified with respect to the examples was put into a mixing aggregate and the liquid temporary binder was poured onto it while mixing. After stirring for about 3-5 minutes, a mixture consisting of the vitrified bond precursor mix and the solid temporary binder was added and the mixing was continued thoroughly for about 10 minutes.

(ii) Sieving

[0262] With reference to the examples given, the mixture obtained in step (i) is screened with a sieve 16 mesh (mesh size 1.18 mm).

(iii) Moulding

[0263] The mixture obtained in step (ii) is put into a mould and formed by pressing to give green bodies. Typical forming pressures were 126-150 kg/cm² for green bodies with an abrasive mix containing 100% 80+ and 21-51 kg/cm² for green bodies with an abrasive mix containing 30% 80, 60+ or T shaped abrasive grain.

(iv) Heat treatment

[0264] With reference to the examples given, the achieved green bodies are dried at a temperature of 130°C and sintered at a temperature of 930°C.

(vii) Finishing

[0265] The finishing operation comprises the grinding of the bore, the lateral surfaces, and the peripheral surface.

Table 1: Composition of the test wheels

Amounts [wt. %]*	Example 1A-1	Example 2A-1	Example 3A-1	Example 1A-2	Comparative Example Ref. 1A-2	Comparative Example Ref. 2A-1	Comparative Example Ref. 3A-1	Comparative Example Ref. 3A-2
Abrasive Grain	Mix 3	Mix 4	Mix 5	Mix 6	Mix 1	Mix 2	Mix 6	Mix 7
shaped abrasive grain	26.55 80+	26.55 60+	26.55 T	88.50 80+				
3M™ Ceramic Abrasive Grain 321						26.55		
Cerpass TGE®, code TGE-0557							26.55	88.50
White fused aluminium oxide	61.95	61.95	61.95	-	88.50	61.95	61.95	-
Vitreous bond	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50
Starch	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Liquid temporary binder mix	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20

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Moulding density [g/cm ³]	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110
Wheel Type**	Type I	Type I	Type I	Type I	Type I	Type I	Type I	Type I

** The Wheel Type relates to the hardness/structure of the wheels and had been classified as Type I or Type II based on the percentage of bond and porosity in the wheel. Because of the higher percentage of bond and less porosity present, wheels of Type II can be considered as acting harder or more rigid under the grinding conditions used as compared to wheels of Type I.

* weight amounts of the green wheels before firing

Table 1 continued

Amounts [wt. %]*	Example 1B-1	Example 2B-1	Example 3B-1	Example 1B-2		
Abrasive Grain	Mix 3	Mix 4	Mix 5	Mix 6		
shaped abrasive grain	25.97 80+	25.97 60+	25.97 T	86.58 80+		
3M™ Ceramic Abrasive Grain 321						
White fused aluminium oxide	60.61	60.61	60.61			
Vitreous bond	13.42	13.42	13.42	13.42		
Starch	0.85	0.85	0.85	0.85		
Liqui temporary binder mix	3.30	3.30	3.30			
Moulding density [g/cm ³]	2.150	2.150	2.150	2.150		
Wheel Type**	Type II	Type II	Type II	Type II		

* weight amounts of the green wheels before firing

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** The Wheel Type relates to the hardness/structure of the wheels and had been classified as Type I or Type II based on the percentage of bond and porosity in the wheel. Because of the higher percentage of bond and the less porosity present, wheels of Type II can be considered as acting harder or more rigid

C. Testing procedure

[0266] The wheels prepared as in the examples given were tested in a cylindrical grinding application in order to establish the grinding performance of the wheels.

[0267] The grinding tests were performed using the following grinding conditions:

Grinding Process:	outer diameter (OD-) grinding
Machine:	UVA Johansson 10MD; 18.5 kW, year of construction 1979 (rebuilt)
Work piece:	bearing steel; Ovako 824, Ovako Hofors AB, Sweden 1.3537 (100CrMo7) according to EN ISO 683-17:1999, 62-64 HRc, diameter 100 mm, length 20 mm
Parameters:	operating speed of grinding wheel: 45 m/s
Dressing:	Multi-point diamond dresser, V448-0,8x4-4 bars, Kucher GmbH, Germany, synthetic diamond, width 15 mm, length 28 mm, traverse speed 350 mm/min

[0268] Using all wheels, three sets of grinding tests were performed.

[0269] Test Series (I) used a specific material removal rate of Q'_W 2.5 mm³/mm/s (infeed: 0.006 mm/turn of work piece; peripheral speed of work piece: 25 m/min).

[0270] Test Series (II) used more severe grinding conditions by applying a specific material removal rate of Q'_W 5 mm³/mm/s (infeed: 0.010 mm/turn of work piece; peripheral speed of work piece: 30 m/min).

[0271] Test series (III), using a specific material removal rate of Q'_W 2.5 mm³/mm/s (infeed: 0.006 mm/turn of work piece; peripheral speed of work piece: 25 m/min) to remove 1.2 mm of work piece in radius following by 5 s of outspark was chosen to characterise the surface quality of the work piece.

[0272] The power drawn was recorded as a function of the grinding time. The results of Test Series (I) are shown in Fig. 1 and Fig. 2. The results of Test Series (II) are shown in Fig. 3 and Fig. 4.

[0273] Typically grinding curves of this type are cyclical: The power drawn (to be discussed) (kilowatts) increases over time as the grinding forces increase. When the forces get high enough the wheel breaks down, breaking and ejecting grit particles and then the grinding power consumption (grinding force) decreases. At this point dressing of the grinding wheel has to be set up in order to avoid defects at the workpiece to be abraded and in order to provide for constant abrading performance of the grinding wheel. Then the grinding cycle has to be started again. What is desired is a grinding wheel having a long cycle period (in terms of constant power drawn), indicating good form holding and long total service life of the wheel.

[0274] For each wheel the grinding test was operated until the power consumption fell below the power consumption at the initial grinding level. This was considered the test endpoint. Due to their long service life the tests of Test Series (I) using the wheels of all examples excluding Example Ref. 1A-2 and Ref. 2A-1, and the tests of Test Series (II) using the grinding wheels of Examples 1A-2 and 1B-2 (100% 80+) were ended before reaching this point.

[0275] In addition, the surface roughness R_a of the workpiece after the grinding according to Test Series III has been determined with a device of type SURFTEST SJ-210 of Mitutojo. The results of the Type (I)-wheels are summarized in Fig. 5.

D. Results

[0276] A comparison of the results obtained under Test Series I and II shows the higher grinding performance of the examples given by increasing the specific material removal rate (Fig. 1-4). While in Test Series (I) (Q'_W 2.5 mm³/mm/s) all variants comprising non seeded sol gel derived aluminium oxide refer to a long service life (Fig. 1 and Fig. 2, examples excluding the Comparative Examples Ref. 1A-2, Ref. 2A-1, Ref. 3A-1, and Ref. 3A-2), differences in the power drawn can be seen in Fig. 3 and Fig. 4 when applying the grinding conditions of Test Series (II) comprising a specific material removal rate Q'_W of 5 mm³/mm/s.

[0277] Fig. 3 and Fig. 4 illustrate a marked increase in the period of the grinding cycle when using grinding wheels containing shaped abrasive particles in accordance with the present invention in comparison to the variants comprising white fused aluminium oxide or 3M™ Ceramic Abrasive Grain 321 or extruded Cerpass TGE® (Comparative Examples Ref. 1A-2 or Ref. 2A-1, or Ref. 3A-1) resp., and confirm the increase of the service life. In example, the period for the grinding cycle of Example 1A-1 in comparison to Ref. 2A-1 is nearly doubled, thus resulting in a longer dressing interval. Considering grinding wheels with abrasive mixes consisting of 100% shaped abrasive particles in accordance with the present invention (Example 1A-2) as well as 100% extruded Cerpass TGE® (Comparative Example Ref. 3A-2) Example 1A-2 shows a marked increase in service life. The testing of Example 1A-2 was terminated artificially because of the constant power drawn during a certain grinding duration.

[0278] With reference to the examples comprising shaped abrasive particles in accordance with the present invention

an influence of the abrasive grain size and the amount of the abrasive grain portion can be seen. Increasing the abrasive grain portion effects longer service life. This can be seen from Examples 1A-2 and 1B-2 in comparison to examples 1A-1 and 1B-1, each containing shaped abrasive particles 80+. Using the same portion of the shaped abrasive particle of the invention, examples 2A-1 and 2B-1, containing shaped abrasive particles 60+, show the influence of the grain size and an increase of the service life by reducing the wear of the shaped abrasive particles in comparison to the Examples 1A-1 and 1B-1, comprising shaped abrasive particles 80+.

[0279] In sum, the use of shaped abrasive grains in a vitrified bond can provide abrasive grinding wheels exhibiting a long and stable grinding curve in grinding applications, particularly under more severe grinding conditions, as for example shown in Test Series II. Surprisingly, the service life of the wheels increased when tested using a higher specific removal rate ($Q'_w = 5.0 \text{ mm}^3/\text{mm}/\text{sunit}$). Increasing the amount of shaped abrasive particles according to the present invention can provide an extremely long grinding cycle.

[0280] In addition, the use of shaped abrasive grains has been found to provide improved surface finish as evident from a comparison of the examples for Wheel Type I given and shown in Fig. 5. With respect to the grinding practice, it has to be stated that deviation of the results is low. Because of its narrow range the results of the surface roughness R_a are not described in detail.

[0281] With respect to the results obtained it is also to be noted that the grinding tests involved a specific grinding machine built in 1979. The use of a more recently constructed machine is expected to provide even better results since higher values for Q'_w could be accomplished.

Claims

1. A bonded abrasive article comprising shaped abrasive particles and a bonding medium comprising a vitreous bond, said shaped abrasive particles each comprising a first side and a second side separated by a thickness t , wherein said first side is a first face having a perimeter of a first geometric shape, wherein the thickness t is smaller than the length of the shortest side-related dimension of the particle, wherein the second side either comprises a vertex or a ridge line or a second face having a perimeter of a second geometric shape which may be the same or different to the first geometric shape, wherein said first and second geometric shapes are independently selected from regular and irregular polygonal shapes, wherein the length of the shortest side related dimension of the particle is the length of the shortest facial dimension of the first face (if the particle has no second face) or is the length of the shortest facial dimension of the larger face of the particle (if the particle has a second face), wherein said vitreous bond comprises, based on the total weight of the vitreous bond, 25 to 90 % by weight of SiO_2 .
2. The article according to claim 1, wherein the shaped abrasive particles are ceramic shaped abrasive particles.
3. The article according to claim 1 or 2, wherein the shaped abrasive particles comprise alpha alumina.
4. The article according to any of claims 1 to 3, wherein the shaped abrasive particles comprise seeded or non seeded sol-gel derived alpha alumina.
5. The article according to any of claims 1 to 4, further comprising secondary abrasive particles.
6. The article according to claim 5, wherein the shaped and secondary abrasive particles are independently selected from particles of fused aluminum oxide materials, heat treated aluminum oxide materials, ceramic aluminum oxide materials, sintered aluminum oxide materials, silicon carbide materials, titanium diboride, boron carbide, tungsten carbide, titanium carbide, diamond, cubic boron nitride, garnet, fused alumina-zirconia, sol-gel derived abrasive particles, cerium oxide, zirconium oxide, titanium oxide or a combination thereof.
7. The article according to claim 5 or 6 wherein the secondary abrasive particles are selected from crushed abrasive particles having a specified nominal grade.
8. The article according to claim 7, wherein the crushed abrasive particles are of a smaller size than the shaped abrasive particles.
9. The article according to any of claims 1 to 8 comprising 10 to 80 % by volume of said shaped abrasive particles and 1 to 60 % by volume of said bonding medium.

10. The article according to any of claims 1 to 9, wherein said vitreous bond comprises, based on the total weight of the vitreous bond, 0 to 40% by weight of B_2O_3 ; 0 to 40% by weight of Al_2O_3 ; 0 to 5% by weight of Fe_2O_3 ; 0 to 5% by weight of TiO_2 ; 0 to 20% by weight of CaO ; 0 to 20% by weight of MgO ; 0 to 20% by weight of K_2O ; 0 to 25% by weight of Na_2O ; 0 to 20% by weight of Li_2O ; 0 to 10% by weight of ZnO ; 0 to 10% by weight of BaO ; and 0 to 5% by weight of metallic oxides.
11. The article according to any of claims 1 to 10, wherein the vitreous bond is obtainable from a vitreous bond precursor composition comprising frit.
12. The article according to any of claims 1 to 11, comprising porosity.
13. The article according to any of claims 5 to 12 wherein the shaped abrasive particles and the secondary abrasive particles are comprised in a blend, wherein the content of the secondary abrasive particles is up to 95 % by weight based on the total amount of abrasive particles present in the blend.
14. The article according to any of claims 1 to 13, wherein said first geometric shape is selected from triangular shapes and quadrilateral shapes.
15. The article according to any of claims 1 to 14, comprising at least one sidewall.
16. The article according to claim 15, wherein the at least one sidewall is a sloping sidewall.
17. The article according to any of claims 1 to 16, wherein said shaped abrasive particles each comprise at least one shape feature selected from: an opening, at least one recessed (or concave) face; at least one face which is shaped outwardly (or convex); at least one side having a plurality of grooves or ridges; a low roundness factor; a perimeter of the first face comprising one or more corner points having a sharp tip; a second side comprising a second face having a perimeter comprising one or more corner points having a sharp tip; or a combination of one or more of said shape features.
18. The article according to any of claims 1 to 17, wherein the shaped abrasive particles each have an opening.
19. The article according to any of claims 1 to 18, wherein the shaped abrasive particles further comprise a plurality of grooves and/or ridges on the second side.
20. The article according to any of claims 1 to 19, wherein the second side comprises a vertex or a ridge line or a second face.
21. The article according to claim 20, wherein the second side comprises a second face separated from the first side by thickness t and at least one sidewall connecting the second face and the first face.
22. The article according to claim 21 wherein the first and second geometric shapes have identical geometric shapes which may or may not be different in size.
23. The article according to any of claims 21 to 22, wherein the first face and the second face are substantially parallel or nonparallel to each other.
24. The article according to any of claims 21 to 23, wherein the first and the second face are substantially planar.
25. The article according to any of claims 21 to 24, wherein at least one of the first and second face is a non-planar face.
26. The article according to claim 25, wherein the first face is recessed or concave and the second face is substantially planar or the first face is convex and the second face is recessed or concave or the first face is recessed or concave and the second face is recessed or concave.
27. The article according to any of claims 21 to 26, wherein the second side comprises a second face and four facets intersecting the second face at a draft angle α forming a truncated pyramid.
28. The article according to claim 20, wherein the second side comprises a vertex separated from the first side by

thickness t and at least one sidewall connecting the vertex and the perimeter of the first face.

29. The article according to claim 28, wherein the perimeter of the first face is trilateral, quadrilateral or higher polygonal and wherein the second side comprises a vertex and the corresponding number of facets for forming a pyramid.

30. The article according to claim 29, wherein the perimeter of the first face is trilateral and wherein the shaped abrasive particles have four major sides joined by six common edges, wherein each one of the four major sides contacts three other of the four major sides, and wherein the six common edges have substantially the same length.

31. The article according to claim 20, wherein the second side comprises a ridge line separated from the first side by thickness t and at least one sidewall connecting the ridge line and the perimeter of the first face.

32. The article according to claim 31, wherein the sidewall comprises one or more facets connecting the ridge line and the perimeter of the first face.

33. The article according to claim 31 or 32, wherein the first geometric shape is selected from quadrilateral geometric shapes and the sidewall comprises four facets forming a roof-shaped particle.

34. The article according to any of claims 1 to 33 having a three dimensional shape selected from the shape of a wheel, honing stone, grinding segment, mounted points, or other shapes.

35. The article according to any of claims 1 to 34, wherein the article comprises a wheel.

36. The article according to any of claims 34 or 35, wherein the wheel is selected from grinding wheels for cylindrical grinding, centerless grinding, surface and profile grinding, reciprocating grinding, creep-feed grinding, grinding in generating methods of gears, threads, tools, camshafts, crankshafts, bearings, and guard rails.

37. The article according to any of claims 1 to 36, wherein the shaped abrasive particles are homogeneously distributed in the abrasive article.

38. The article according to any of claims 1 to 36, wherein the shaped abrasive particles are non-homogeneously distributed in the abrasive article.

39. The article according to claim 38, which is or comprises a bonded abrasive wheel, the wheel comprising an outer zone and an inner zone, wherein the composition of the inner and outer zone differ in one or more aspects selected from the composition of the bond, the shape of abrasive particles, the grit size of abrasive particle, and the amount of abrasive particles.

40. Use of an article according to any of claims 1 to 39 in high performance grinding applications.

41. Use according to claim 40 for outer diameter grinding with a Q'_w of at least $1.5 \text{ mm}^3/\text{mm}/\text{sec}$, inner diameter grinding with a Q'_w of at least $1 \text{ mm}^3/\text{mm}/\text{sec}$, surface grinding with a Q'_w of at least $1.5 \text{ mm}^3/\text{mm}/\text{sec}$, profile grinding with a Q'_w of at least $3 \text{ mm}^3/\text{mm}/\text{sec}$, profile grinding with generating method with a Q'_w of at least $8 \text{ mm}^3/\text{mm}/\text{sec}$, creep-feed grinding with a Q'_w of at least $4 \text{ mm}^3/\text{mm}/\text{sec}$, and camshaft grinding with a Q'_w of at least $8 \text{ mm}^3/\text{mm}/\text{sec}$.

42. Use of an article according to any of claims 1 to 39 for abrading a workpiece material selected from steels, non-ferrous metals, alloys, hard metals, ceramics and glasses.

43. Method for abrading a workpiece, the method comprising frictionally contacting at least a portion of the abrasive article according to any of claims 1 to 39 with a surface of a workpiece; and moving at least one of the workpiece or the abrasive article to abrade at least a portion of the surface of the workpiece.

Patentansprüche

1. Gebundener Schleifgegenstand, umfassend geformte Schleifeteilchen und ein Bindemittel, umfassend eine glasartige Bindung, wobei die geformten Schleifeteilchen jeweils eine erste Seite und eine zweite Seite, die durch eine Dicke t voneinander getrennt sind, umfassen, wobei die erste Seite eine erste Fläche mit einem Umfang einer ersten

geometrischen Form ist, wobei die Dicke t kleiner als die Länge der kürzesten seitenbezogenen Abmessung des Teilchens ist,

wobei die zweite Seite entweder einen Scheitelpunkt oder eine Kantenlinie oder eine zweite Fläche mit einem Umfang einer zweiten geometrischen Form, die gleich oder unterschiedlich von der ersten geometrischen Form sein kann, umfasst,

wobei die erste und die zweite geometrische Form unabhängig voneinander aus regelmäßigen und unregelmäßigen vieleckigen Formen ausgewählt sind,

wobei die Länge der kürzesten seitenbezogenen Abmessung des Teilchens die Länge der kürzesten Flächenabmessung der ersten Fläche ist (wenn das Teilchen keine zweite Fläche aufweist) oder die Länge der kürzesten Flächenabmessung der größeren Fläche des Teilchens ist (wenn das Teilchen eine zweite Fläche aufweist),

wobei die glasartige Bindung, bezogen auf das Gesamtgewicht der glasartigen Bindung, 25 bis 90 Gew.-% SiO_2 umfasst.

2. Gegenstand nach Anspruch 1, wobei die geformten Schleifeteilchen geformte Keramiksleifeteilchen sind.

3. Gegenstand nach Anspruch 1 oder 2, wobei die geformten Schleifeteilchen alpha-Aluminiumoxid umfassen.

4. Gegenstand nach einem der Ansprüche 1 bis 3, wobei die geformten Schleifeteilchen angeimpftes oder nicht angeimpftes, von Sol-Gel abgeleitetes alpha-Aluminiumoxid umfassen.

5. Gegenstand nach einem der Ansprüche 1 bis 4, der ferner sekundäre Schleifeteilchen umfasst.

6. Gegenstand nach Anspruch 5, wobei die geformten und die sekundären Schleifeteilchen unabhängig voneinander aus Teilchen von geschmolzenen Aluminiumoxidmaterialien, wärmebehandelten Aluminiumoxidmaterialien, keramischen Aluminiumoxidmaterialien, gesinterten Aluminiumoxidmaterialien, Siliciumcarbidmaterialien, Titandiborid, Borcarbid, Wolframcarbid, Titancarbid, Diamant, kubischem Bornitrid, Granat, geschmolzenem Aluminiumoxid-Zirkoniumdioxid, von Sol-Gel abgeleiteten Schleifeteilchen, Ceroxid, Zirkoniumoxid, Titanoxid oder einer Kombination davon ausgewählt sind.

7. Gegenstand nach Anspruch 5 oder 6, wobei die sekundären Schleifeteilchen aus zerkleinerten Schleifeteilchen mit einer bestimmten Nennkörnung ausgewählt sind.

8. Gegenstand nach Anspruch 7, wobei die zerkleinerten Schleifeteilchen von kleinerer Größe sind als die geformten Schleifeteilchen.

9. Gegenstand nach einem der Ansprüche 1 bis 8, umfassend 10 bis 80 Vol.-% der geformten Schleifeteilchen und 1 bis 60 Vol.-% des Bindemittels.

10. Gegenstand nach einem der Ansprüche 1 bis 9, wobei die glasartige Bindung, bezogen auf das Gesamtgewicht der glasartigen Bindung, 0 bis 40 Gew.-% B_2O_3 ; 0 bis 40 Gew.-% Al_2O_3 ; 0 bis 5 Gew.-% Fe_2O_3 ; 0 bis 5 Gew.-% TiO_2 ; 0 bis 20 Gew.-% CaO ; 0 bis 20 Gew.-% MgO ; 0 bis 20 Gew.-% K_2O ; 0 bis 25 Gew.-% Na_2O ; 0 bis 20 Gew.-% Li_2O ; 0 bis 10 Gew.-% ZnO ; 0 bis 10 Gew.-% BaO und 0 bis 5 Gew.-% Metalloxide umfasst.

11. Gegenstand nach einem der Ansprüche 1 bis 10, wobei die glasartige Bindung aus einer Vorläuferzusammensetzung für glasartige Bindung, die Fritte umfasst, erhältlich ist.

12. Gegenstand nach einem der Ansprüche 1 bis 11, der Porosität umfasst.

13. Gegenstand nach einem der Ansprüche 5 bis 12, wobei die geformten Schleifeteilchen und die sekundären Schleifeteilchen in einer Mischung enthalten sind, wobei der Gehalt der sekundären Schleifeteilchen bis zu 95 Gew.-%, bezogen auf die Gesamtmenge von in der Mischung vorhandenen Schleifeteilchen, beträgt.

14. Gegenstand nach einem der Ansprüche 1 bis 13, wobei die erste geometrische Form aus dreieckigen Formen und vierseitigen Formen ausgewählt ist.

15. Gegenstand nach einem der Ansprüche 1 bis 14, der mindestens eine Seitenwand umfasst.

16. Gegenstand nach Anspruch 15, wobei die mindestens eine Seitenwand eine geneigte Seitenwand ist.

17. Gegenstand nach einem der Ansprüche 1 bis 16, wobei die geformten Schleifeteilchen jeweils mindestens ein Formmerkmal umfassen, das ausgewählt ist aus: einer Öffnung, mindestens einer vertieften (oder konkaven) Fläche; mindestens einer Fläche, die nach außen geformt (oder konvex) ist; mindestens einer Seite, die mehrere Rillen oder Kanten aufweist; einem niedrigen Rundungsfaktor; einem Umfang der ersten Fläche, der einen oder mehrere Eckpunkte mit einer scharfen Spitze umfasst; einer zweiten Seite, die eine zweite Fläche mit einem Umfang umfasst, der einen oder mehrere Eckpunkte mit einer scharfen Spitze umfasst; oder einer Kombination eines oder mehrerer der Formmerkmale.
18. Gegenstand nach einem der Ansprüche 1 bis 17, wobei die geformten Schleifeteilchen jeweils eine Öffnung aufweisen.
19. Gegenstand nach einem der Ansprüche 1 bis 18, wobei die geformten Schleifeteilchen ferner mehrere Rillen und/oder Kanten auf der zweiten Seite umfassen.
20. Gegenstand nach einem der Ansprüche 1 bis 19, wobei die zweite Seite einen Scheitelpunkt oder eine Kantenlinie oder eine zweite Fläche umfasst.
21. Gegenstand nach Anspruch 20, wobei die zweite Seite eine zweite Fläche umfasst, die von der ersten Seite durch eine Dicke t getrennt ist, und wobei mindestens eine Seitenwand die zweite Fläche und die erste Fläche verbindet.
22. Gegenstand nach Anspruch 21, wobei die erste und die zweite geometrische Form identische geometrische Formen aufweisen, die in der Größe unterschiedlich sein können oder nicht.
23. Gegenstand nach einem der Ansprüche 21 bis 22, wobei die erste Fläche und die zweite Fläche im Wesentlichen parallel oder nicht parallel zueinander sind.
24. Gegenstand nach einem der Ansprüche 21 bis 23, wobei die erste und die zweite Fläche im Wesentlichen eben sind.
25. Gegenstand nach einem der Ansprüche 21 bis 24, wobei mindestens eine der ersten und der zweiten Fläche eine nicht ebene Fläche ist.
26. Gegenstand nach Anspruch 25, wobei die erste Fläche vertieft oder konkav ist und die zweite Fläche im Wesentlichen eben ist oder die erste Fläche konvex ist und die zweite Fläche vertieft oder konkav ist oder die erste Fläche vertieft oder konkav ist und die zweite Fläche vertieft oder konkav ist.
27. Gegenstand nach einem der Ansprüche 21 bis 26, wobei die zweite Seite eine zweite Fläche und vier Facetten umfasst, die die zweite Fläche in einem Schrägenwinkel α schneiden, wobei ein Pyramidenstumpf gebildet wird.
28. Gegenstand nach Anspruch 20, wobei die zweite Seite einen Scheitelpunkt umfasst, getrennt von der ersten Seite durch eine Dicke t , und wobei mindestens eine Seitenwand den Scheitelpunkt und den Umfang der ersten Fläche verbindet.
29. Gegenstand nach Anspruch 28, wobei der Umfang der ersten Fläche dreiseitig, vierseitig oder höher polygonal ist und wobei die zweite Seite einen Scheitelpunkt und die entsprechende Anzahl von Facetten zum Bilden einer Pyramide umfasst.
30. Gegenstand nach Anspruch 29, wobei der Umfang der ersten Fläche dreiseitig ist und wobei die geformten Schleifeteilchen vier Hauptseiten aufweisen, die durch sechs gemeinsame Ränder verbunden sind, wobei jede der vier Hauptseiten drei andere der vier Hauptseiten berührt und wobei die sechs gemeinsamen Ränder im Wesentlichen die gleiche Länge aufweisen.
31. Gegenstand nach Anspruch 20, wobei die zweite Seite eine Kantenlinie umfasst, getrennt von der ersten Seite durch eine Dicke t , und wobei mindestens eine Seitenwand die Kantenlinie und den Umfang der ersten Fläche verbindet.
32. Gegenstand nach Anspruch 31, wobei die Seitenwand eine oder mehrere Facetten umfasst, die die Kantenlinie und den Umfang der ersten Fläche verbinden.
33. Gegenstand nach Anspruch 31 oder 32, wobei die erste geometrische Form aus vierseitigen geometrischen Formen

ausgewählt ist und die Seitenwand vier Facetten umfasst, die ein dachförmiges Teilchen bilden.

34. Gegenstand nach einem der Ansprüche 1 bis 33, der eine dreidimensionale Form aufweist, ausgewählt aus der Form einer Scheibe, eines Honsteins, eines Schleifsegments, von Schleifstiften oder anderen Formen.

35. Gegenstand nach einem der Ansprüche 1 bis 34, wobei der Gegenstand eine Scheibe umfasst.

36. Gegenstand nach einem der Ansprüche 34 oder 35, wobei die Scheibe aus Schleifscheiben für Rundschleifen, spitzenloses Schleifen, Plan- und Profilschleifen, Pendelschleifen, Kriechgangschleifen, Schleifverfahren bei der Herstellung von Zahnrädern, Gewinden, Werkzeugen, Nockenwellen, Kurbelwellen, Lagern und Leitschienen ausgewählt ist.

37. Gegenstand nach einem der Ansprüche 1 bis 36, wobei die geformten Schleifeteilchen homogen in dem Schleifgegenstand verteilt sind.

38. Gegenstand nach einem der Ansprüche 1 bis 36, wobei die geformten Schleifeteilchen nicht homogen in dem Schleifgegenstand verteilt sind.

39. Gegenstand nach Anspruch 38, der eine gebundene Schleifscheibe ist oder umfasst, wobei die Scheibe eine äußere Zone und eine innere Zone umfasst, wobei sich die Zusammensetzung der inneren und äußeren Zone in einem oder mehreren Gesichtspunkten unterscheidet, ausgewählt aus der Zusammensetzung der Bindung, der Form der Schleifeteilchen, der Korngröße von Schleifeteilchen und der Menge von Schleifeteilchen.

40. Verwendung eines Gegenstands nach einem der Ansprüche 1 bis 39 in Hochleistungs-Schleifanwendungen.

41. Verwendung nach Anspruch 40 für Außendurchmesserschleifen mit Q'_w von mindestens $1,5 \text{ mm}^3/\text{mm/s}$, Innendurchmesserschleifen mit Q'_w von mindestens $1 \text{ mm}^3/\text{mm/s}$, Flachsleifen mit Q'_w von mindestens $1,5 \text{ mm}^3/\text{mm/s}$, Profilschleifen mit Q'_w von mindestens $3 \text{ mm}^3/\text{mm/s}$, Profilschleifen in einem Herstellungsverfahren mit Q'_w von mindestens $8 \text{ mm}^3/\text{mm/s}$, Kriechgangschleifen mit Q'_w von mindestens $4 \text{ mm}^3/\text{mm/s}$ und Nockenwellenschleifen mit Q'_w von mindestens $8 \text{ mm}^3/\text{mm/s}$.

42. Verwendung eines Gegenstands nach einem der Ansprüche 1 bis 39 zum Abschleifen eines Werkstückmaterials, ausgewählt aus Stählen, nicht eisenhaltigen Metallen, Legierungen, Hartmetallen, Keramiken und Gläsern.

43. Verfahren zum Abschleifen eines Werkstücks, wobei das Verfahren das Inkontaktbringen von mindestens einem Abschnitt des Schleifgegenstands nach einem der Ansprüche 1 bis 39 mit einer Oberfläche eines Werkstücks unter Reibung und das Bewegen von mindestens einem von dem Werkstück oder dem Schleifgegenstand, um mindestens einen Abschnitt der Oberfläche des Werkstücks abzuschleifen, umfasst.

Revendications

1. Article abrasif lié comprenant des particules abrasives profilées et un milieu de liaison comprenant une liaison vitreuse, lesdites particules abrasives profilées comprenant chacune un premier côté et un deuxième côté séparés par une épaisseur t , dans lequel ledit premier côté est une première face ayant un périmètre d'une première forme géométrique, dans lequel l'épaisseur t est plus petite que la longueur de la dimension se rapportant au côté le plus court de la particule, dans lequel le deuxième côté comprend soit un sommet soit une ligne de crête soit une deuxième face ayant un périmètre d'une deuxième forme géométrique qui peut être identique ou différente par rapport à la première forme géométrique, dans lequel lesdites première et deuxième formes géométriques sont indépendamment choisies parmi des formes polygonales régulières et irrégulières, dans lequel la longueur de la dimension se rapportant au côté le plus court de la particule est la longueur de la dimension faciale la plus courte de la première face (si la particule n'a aucune deuxième face) ou est la longueur de la dimension faciale la plus courte de la face plus grande de la particule (si la particule a une deuxième face), dans lequel ladite liaison vitreuse comprend, sur la base du poids total de la liaison vitreuse, 25 à 90 % en poids de SiO_2 .

2. Article selon la revendication 1, dans lequel les particules abrasives profilées sont des particules abrasives profilées céramiques.
3. Article selon la revendication 1 ou 2, dans lequel les particules abrasives profilées comprennent de l'alpha-alumine.
4. Article selon l'une quelconque des revendications 1 à 3, dans lequel les particules abrasives profilées comprennent de l'alpha-alumine dérivée de sol-gelensemencé ou nonensemencé.
5. Article selon l'une quelconque des revendications 1 à 4, comprenant en outre des particules abrasives secondaires.
6. Article selon la revendication 5, dans lequel les particules abrasives profilées et secondaires sont indépendamment choisies parmi des particules de matériaux d'oxyde d'aluminium fondu, de matériaux d'oxyde d'aluminium traité thermiquement, de matériaux d'oxyde d'aluminium céramique, de matériaux d'oxyde d'aluminium fritté, de matériaux de carbure de silicium, de diborure de titane, de carbure de bore, de carbure de tungstène, de carbure de titane, de diamant, de nitrure de bore cubique, de grenat, d'alumine-zircone fusionnée, de particules abrasives dérivées de sol-gel, d'oxyde de cérium, d'oxyde de zirconium, d'oxyde de titane ou d'une combinaison de ceux-ci.
7. Article selon la revendication 5 ou 6, dans lequel les particules abrasives secondaires sont choisies parmi des particules abrasives concassées ayant un calibre nominal spécifié.
8. Article selon la revendication 7, dans lequel les particules abrasives concassées sont d'une taille plus petite que les particules abrasives profilées.
9. Article selon l'une quelconque des revendications 1 à 8, comprenant 10 à 80 % en volume desdites particules abrasives profilées et 1 à 60 % en volume dudit milieu de liaison.
10. Article selon l'une quelconque des revendications 1 à 9, dans lequel ladite liaison vitreuse comprend, sur la base du poids total de la liaison vitreuse, 0 à 40 % en poids de B_2O_3 ; 0 à 40 % en poids de Al_2O_3 ; 0 à 5 % en poids de Fe_2O_3 ; 0 à 5 % en poids de TiO_2 ; 0 à 20 % en poids de CaO ; 0 à 20 % en poids de MgO ; 0 à 20 % en poids de K_2O ; 0 à 25 % en poids de Na_2O ; 0 à 20 % en poids de Li_2O ; 0 à 10 % en poids de ZnO ; 0 à 10 % en poids de BaO ; et 0 à 5 % en poids d'oxydes métalliques.
11. Article selon l'une quelconque des revendications 1 à 10, dans lequel la liaison vitreuse peut être obtenue à partir d'une composition de précurseur de liaison vitreuse comprenant une fritte.
12. Article selon l'une quelconque des revendications 1 à 11, comprenant une porosité.
13. Article selon l'une quelconque des revendications 5 à 12, dans lequel les particules abrasives profilées et les particules abrasives secondaires sont comprises dans un mélange, dans lequel la teneur des particules abrasives secondaires va jusqu'à 95 % en poids sur la base de la quantité totale des particules abrasives présentes dans le mélange.
14. Article selon l'une quelconque des revendications 1 à 13, dans lequel ladite première forme géométrique est choisie parmi des formes triangulaires et des formes quadrilatérales.
15. Article selon l'une quelconque des revendications 1 à 14, comprenant au moins une paroi latérale.
16. Article selon la revendication 15, dans lequel ladite au moins une paroi latérale est une paroi latérale inclinée.
17. Article selon l'une quelconque des revendications 1 à 16, dans lequel lesdites particules abrasives profilées comprennent chacune au moins une caractéristique de forme choisie parmi : une ouverture, au moins une face en retrait (ou concave) ; au moins une face qui est profilée vers l'extérieur (ou convexe) ; au moins un côté ayant une pluralité de rainures ou de crêtes ; un faible facteur de rotondité ; un périmètre de la première face comprenant un ou plusieurs points de coin ayant une pointe effilée ; un deuxième côté comprenant une deuxième face ayant un périmètre comprenant un ou plusieurs points de coin ayant une pointe effilée ; ou une combinaison d'une ou plusieurs parmi lesdites caractéristiques de forme.
18. Article selon l'une quelconque des revendications 1 à 17, dans lequel les particules abrasives profilées ont chacune

une ouverture.

19. Article selon l'une quelconque des revendications 1 à 18, dans lequel les particules abrasives profilées comprennent en outre une pluralité de rainures et/ou de crêtes sur le deuxième côté.

20. Article selon l'une quelconque des revendications 1 à 19, dans lequel le deuxième côté comprend un sommet ou une ligne de crête ou une deuxième face.

21. Article selon la revendication 20, dans lequel le deuxième côté comprend une deuxième face séparée du premier côté par une épaisseur t et au moins une paroi latérale reliant la deuxième face et la première face.

22. Article selon la revendication 21, dans lequel les première et deuxième formes géométriques ont des formes géométriques identiques qui peuvent être ou non différentes en taille.

23. Article selon l'une quelconque des revendications 21 à 22, dans lequel la première face et la deuxième face sont essentiellement parallèles ou non parallèles l'une par rapport à l'autre.

24. Article selon l'une quelconque des revendications 21 à 23, dans lequel la première et la deuxième face sont essentiellement planes.

25. Article selon l'une quelconque des revendications 21 à 24, dans lequel au moins l'une de la première et de la deuxième face est une face non plane.

26. Article selon la revendication 25, dans lequel la première face est en retrait ou concave et la deuxième face est essentiellement plane ou la première face est convexe et la deuxième face est en retrait ou concave ou la première face est en retrait ou concave et la deuxième face est en retrait ou concave.

27. Article selon l'une quelconque des revendications 21 à 26, dans lequel le deuxième côté comprend une deuxième face et quatre facettes croisant la deuxième face à un angle d'ébauche α formant une pyramide tronquée.

28. Article selon la revendication 20, dans lequel le deuxième côté comprend un sommet séparé du premier côté par une épaisseur t et au moins une paroi latérale reliant le sommet et le périmètre de la première face.

29. Article selon la revendication 28, dans lequel le périmètre de la première face est trilatéral, quadrilatéral ou polygonal d'ordre plus élevé et dans lequel le deuxième côté comprend un sommet et le nombre correspondant de facettes pour former une pyramide.

30. Article selon la revendication 29, dans lequel le périmètre de la première face est trilatéral et dans lequel les particules abrasives profilées ont quatre côtés principaux joints par six bords communs, dans lequel chacun des quatre côtés principaux vient en contact avec trois autres des quatre côtés principaux, et dans lequel les six bords communs ont essentiellement la même longueur.

31. Article selon la revendication 20, dans lequel le deuxième côté comprend une ligne de crête séparée du premier côté par une épaisseur t et au moins une paroi latérale reliant la ligne de crête et le périmètre de la première face.

32. Article selon la revendication 31, dans lequel la paroi latérale comprend une ou plusieurs facettes reliant la ligne de crête et le périmètre de la première face.

33. Article selon la revendication 31 ou 32, dans lequel la première forme géométrique est choisie parmi des formes géométriques quadrilatérales et la paroi latérale comprend quatre facettes formant une particule en forme de toit.

34. Article selon l'une quelconque des revendications 1 à 33, ayant une forme tridimensionnelle choisie parmi la forme d'une meule, d'une pierre de rodage, d'un segment de rectification, de pointes montées ou d'autres formes.

35. Article selon l'une quelconque des revendications 1 à 34, dans lequel l'article comprend une meule.

36. Article selon l'une quelconque des revendications 34 ou 35, dans lequel la meule est choisie parmi des meules de rectification pour la rectification cylindrique, la rectification sans centre, la rectification de surface et de profil, la

rectification par va-et-vient, la rectification à passe profonde unique, la rectification dans des procédés de production d'engrenages, de filetages, d'outils, d'arbres à cames, de vilebrequins, de roulements et de garde-corps.

- 5 **37.** Article selon l'une quelconque des revendications 1 à 36, dans lequel les particules abrasives profilées sont réparties de façon homogène dans l'article abrasif.
- 10 **38.** Article selon l'une quelconque des revendications 1 à 36, dans lequel les particules abrasives profilées sont réparties de façon non homogène dans l'article abrasif.
- 15 **39.** Article selon la revendication 38, qui est ou qui comprend une meule à abrasif lié, la meule comprenant une zone externe et une zone interne, dans lequel les compositions de la zone interne et de la zone externe diffèrent dans un ou plusieurs aspects choisis parmi la composition de la liaison, la forme des particules abrasives, la taille de grain de la particule abrasive, et la quantité de particules abrasives.
- 20 **40.** Utilisation d'un article selon l'une quelconque des revendications 1 à 39, dans des applications de rectification à hautes performances.
- 25 **41.** Utilisation selon la revendication 40, pour une rectification de diamètre externe avec un Q'_W d'au moins 1,5 mm³/mm/s, une rectification de diamètre interne avec un Q'_W d'au moins 1 mm³/mm/s, une rectification de surface avec un Q'_W d'au moins 1,5 mm³/mm/s, une rectification de profil avec un Q'_W d'au moins 3 mm³/mm/s, une rectification de profil avec procédé de production avec un Q'_W d'au moins 8 mm³/mm/s, une rectification à passe profonde unique avec un Q'_W d'au moins 4 mm³/mm/s, et une rectification d'arbre à cames avec un Q'_W d'au moins 8 mm³/mm/s.
- 30 **42.** Utilisation d'un article selon l'une quelconque des revendications 1 à 39 pour l'abrasion d'un matériau de pièce à usiner choisi parmi des aciers, des métaux non ferreux, des alliages, des métaux durs, des céramiques et des verres.
- 35 **43.** Procédé d'abrasion d'une pièce à usiner, le procédé comprenant la mise en contact par frottement d'au moins une partie de l'article abrasif selon l'une quelconque des revendications 1 à 39 avec une surface d'une pièce à usiner ; et le déplacement d'au moins l'un parmi la pièce à usiner ou l'article abrasif pour abraser au moins une partie de la surface de la pièce à usiner.
- 40
- 45
- 50
- 55

Fig. 1: Q'w 2,5 mm3/mm/s – Type I Wheels

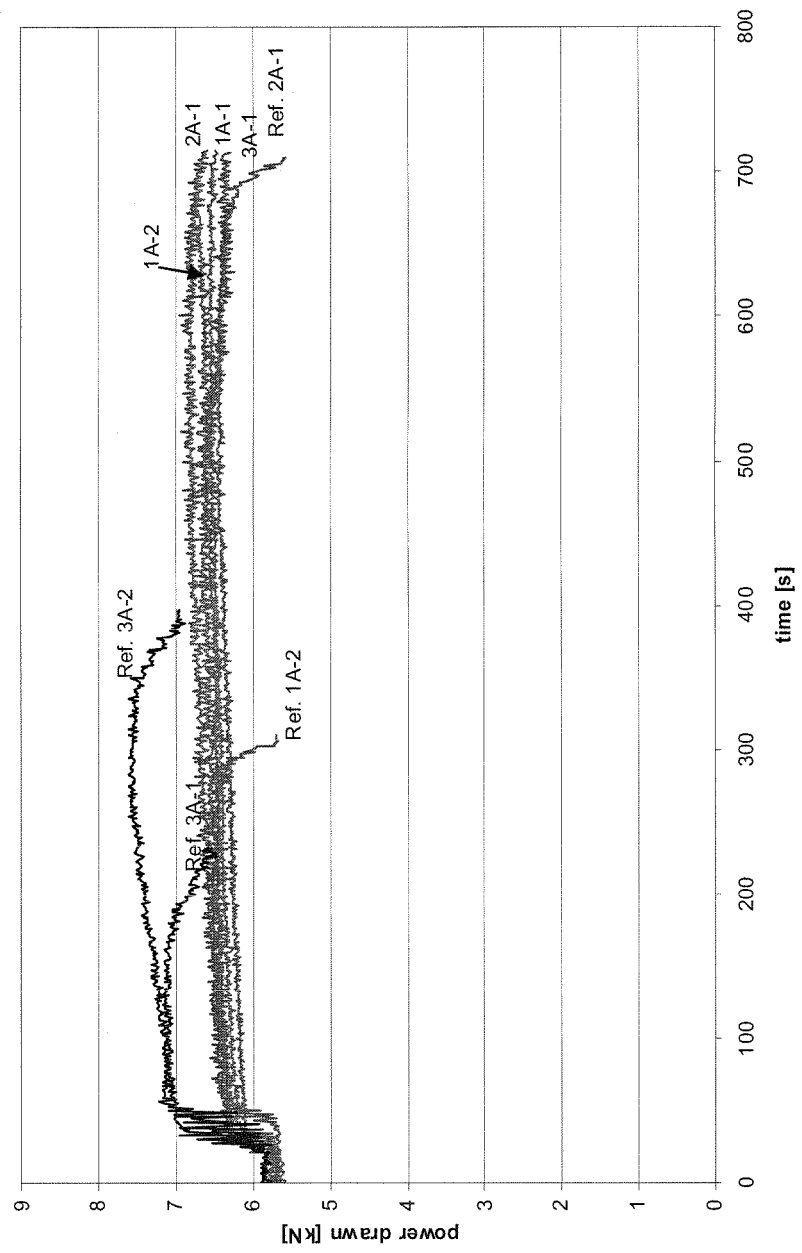


Fig. 2: Q'w 2,5 mm3/mm/s – Type II Wheels

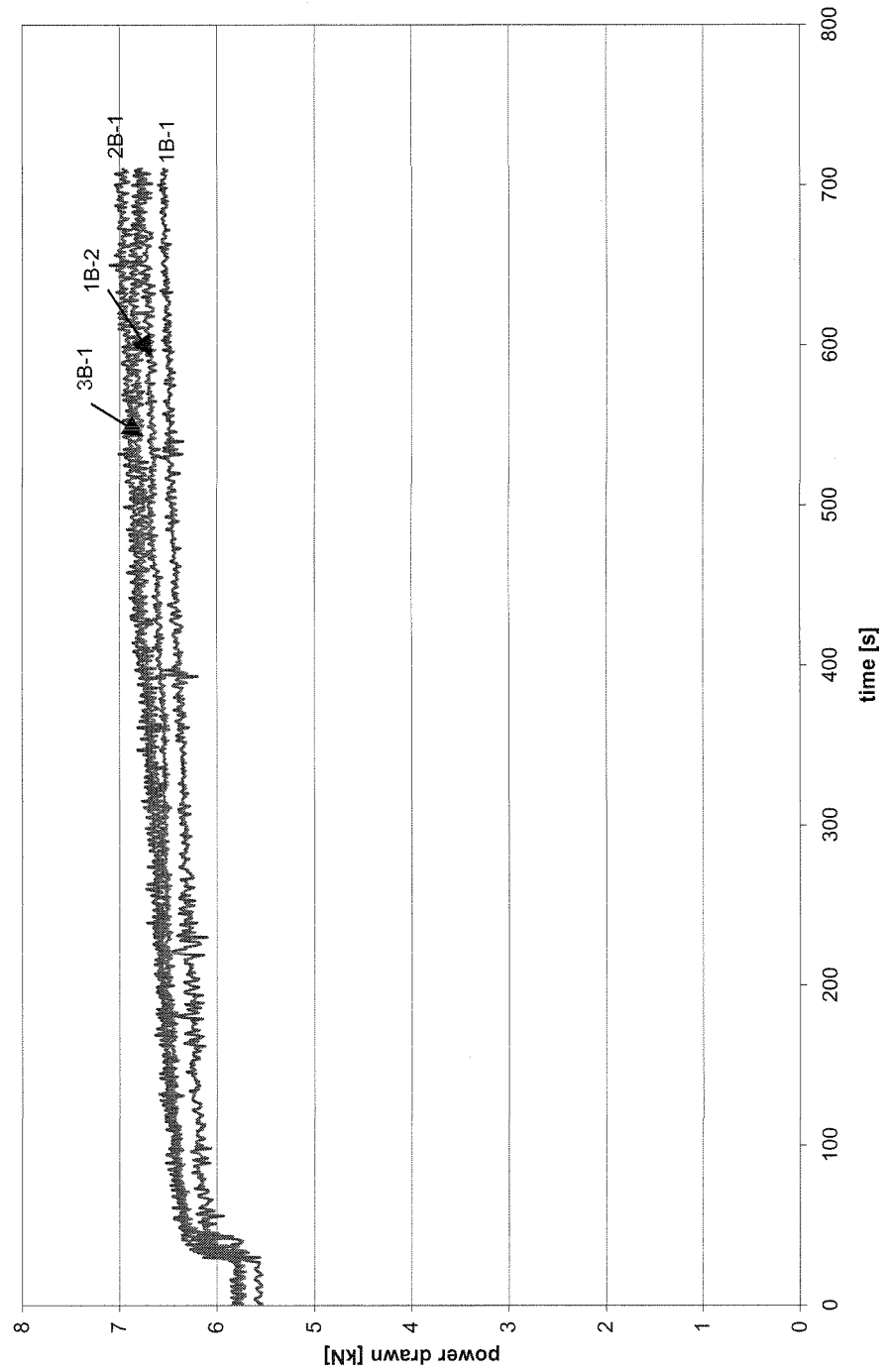


Fig. 3: Q'w 5 mm3/mm/s – Type I Wheels

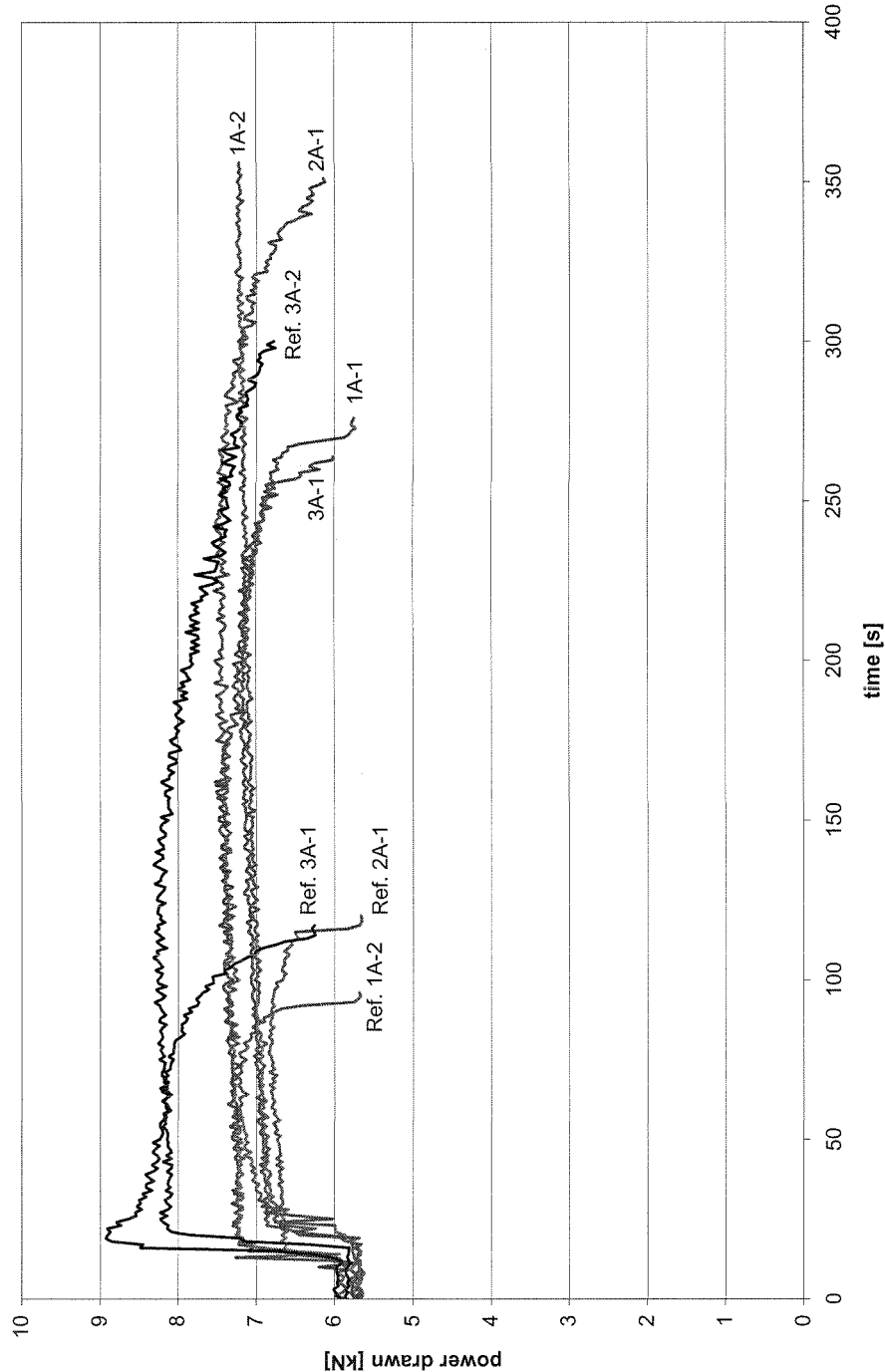


Fig. 4: Q'w 5 mm3/mm/s – Type II Wheels

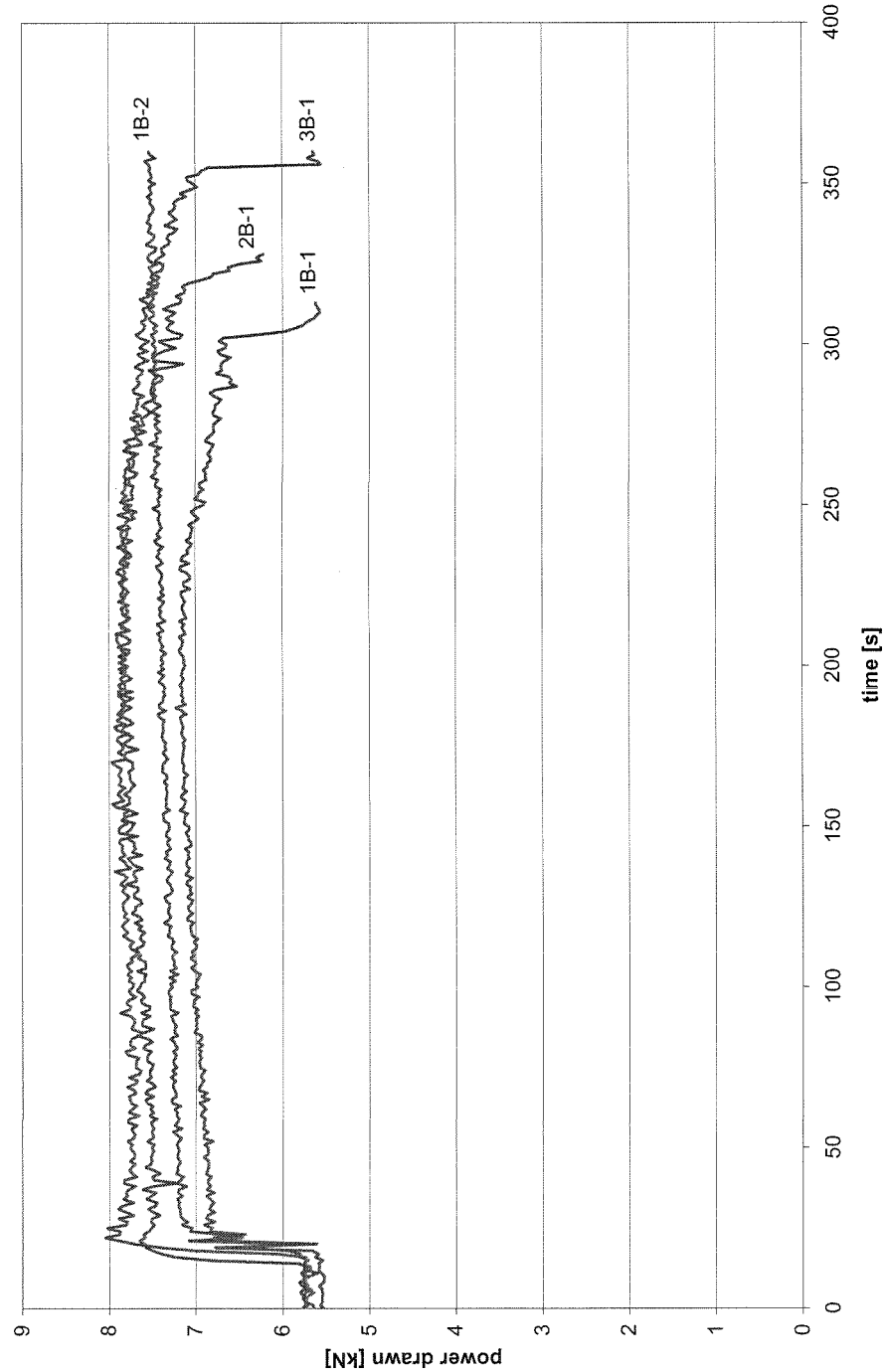


Fig. 5: Surface Roughness R_a – Type I Wheels

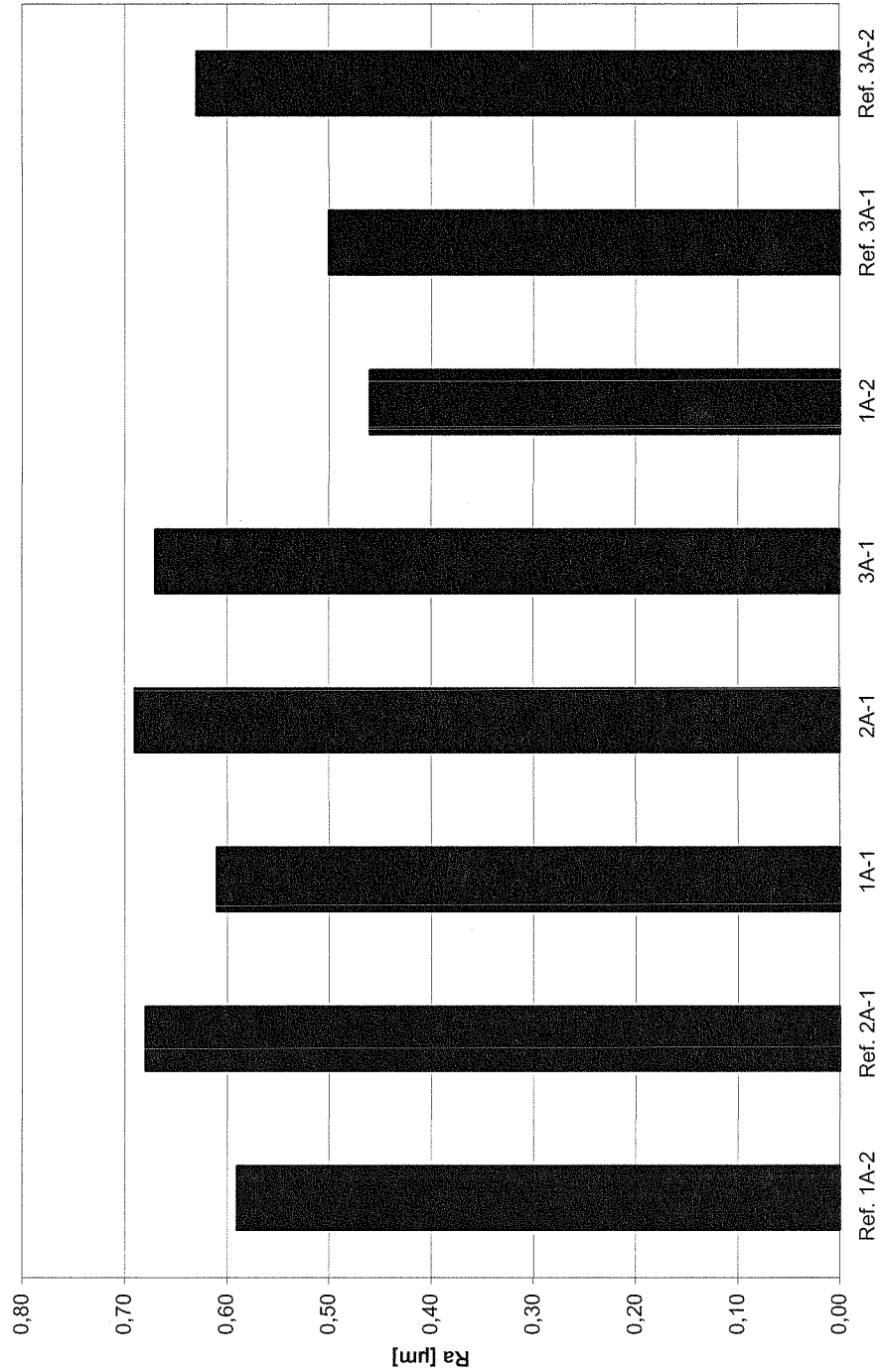


Fig. 6:

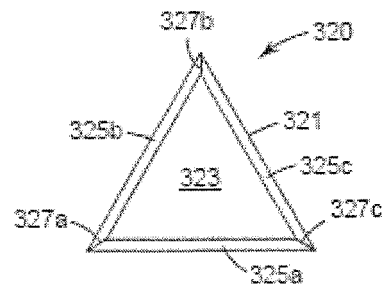


Fig. 6A

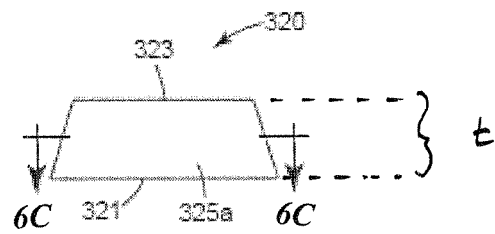


Fig. 6B

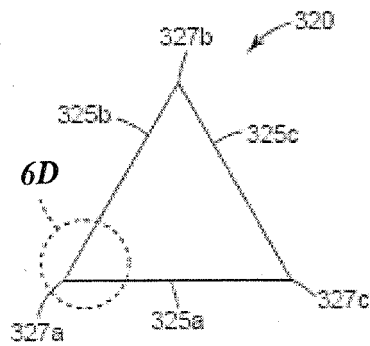


Fig. 6C

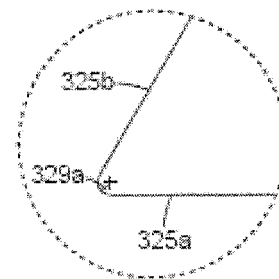


Fig. 6D

REFERENCES CITED IN THE DESCRIPTION

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