ABRASIVE ARTICLE INCLUDING SHAPED ABRASIVE PARTICLES

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Patent Application No. 61/979442, entitled "ABRASIVE ARTICLE INCLUDING SHAPED ABRASIVE PARTICLES," by Kristin BREDER, Jennifer H. CZEREPINSKI, Flavien FREMY, David LOUAPRE, and Samuel S. MARLIN, filed April 14, 2014, which is assigned to the current assignee hereof and incorporated herein by reference in its entirety.

BACKGROUND

Field of the Disclosure

[0002] The following is directed to abrasive articles, and particularly, abrasive articles including shaped abrasive particles.

Description of the Related Art

[0003] Abrasive particles and abrasive articles made from abrasive particles are useful for various material removal operations including grinding, finishing, and polishing. Depending upon the type of abrasive material, such abrasive particles can be useful in shaping or grinding a wide variety of materials and surfaces in the manufacturing of goods. Certain types of abrasive particles have been formulated to date that have particular geometries, such as triangular shaped abrasive particles and abrasive articles incorporating such objects. See, for example, U.S. Pat. Nos. 5,201,916; 5,366,523; and 5,984,988.

[0004] Three basic technologies that have been employed to produce abrasive particles having a specified shape are (1) fusion, (2) sintering, and (3) chemical ceramic. In the fusion process, abrasive particles can be shaped by a chill roll, the face of which may or may not be engraved, a mold into which molten material is poured, or a heat sink material immersed in an aluminum oxide melt. See, for example, U.S. Pat. No. 3,377,660 (disclosing a process including flowing molten abrasive material from a furnace onto a cool rotating casting cylinder, rapidly solidifying the material to form a thin semisolid curved sheet, densifying the semisolid material with a pressure roll, and then partially fracturing the strip of semisolid material by reversing its curvature by pulling it away from the cylinder with a rapidly driven cooled conveyor).

[0005] In the sintering process, abrasive particles can be formed from refractory powders having a particle size of up to 10 micrometers in diameter. Binders can be added to the powders along with a lubricant and a suitable solvent, e.g., water. The resulting mixture mixtures, or slurries can be shaped into platelets or rods of various lengths and diameters. See, for example, U.S. Pat. No. 3,079,242 (disclosing a method of making abrasive particles from calcined bauxite material including (1) reducing the material to a fine powder, (2) compacting under affirmative pressure and forming the fine particles of said powder into grain sized agglomerations, and (3) sintering the agglomerations of particles at a temperature below the fusion temperature of the bauxite to induce limited recrystallization of the particles, whereby abrasive grains are produced directly to size)..

[0006] Chemical ceramic technology involves converting a colloidal dispersion or hydrosol (sometimes called a sol), optionally in a mixture, with solutions of other metal oxide precursors, into a gel or any other physical state that restrains the mobility of the components, drying, and firing to obtain a ceramic material. See, for example, U.S. Pat. Nos. 4,744,802 and 4,848,041. Other relevant disclosures on shaped abrasive particles and associated methods of forming and abrasive articles incorporating such particles are available at: http://www.abel-ip.com/publications/.

[0007] Still, there remains a need in the industry for improving performance, life, and efficacy of abrasive particles, and the abrasive articles that employ abrasive particles.

SUMMARY

[0008] According to one aspect, a shaped abrasive particle includes a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a Shape Index within a range between at least about 0.48 and not greater than about 0.52 and a content of a magnesium-containing species within a range between at least about 1 wt% and not greater than about 4 wt% based on the total weight of the body.

[0009] In yet another aspect, a shaped abrasive particle includes a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body, and a strength within a range between at least about 350 MPa and not greater than about 600 MPa.

[0010] For still another aspect, a shaped abrasive particle includes a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body.

[0011] According to one aspect, a shaped abrasive particle includes a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, and wherein the body consists essentially of alumina and magnesium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

[0013] FIG. 1 includes a portion of a system for forming a particulate material in accordance with an embodiment.

[0014] FIG. 2 includes a portion of the system of FIG. 1 for forming a particulate material in accordance with an embodiment.

[0015] FIG. 3 includes a cross-sectional illustration of a shaped abrasive particle for illustration of certain features according to embodiments.

[0016] FIG. 4 includes a side view of a shaped abrasive particle and percentage flashing according to an embodiment.

[0017] FIG. 5A includes an illustration of a bonded abrasive article incorporating the abrasive particulate material in accordance with an embodiment.

[0018] FIG. 5B includes a cross-sectional illustration of a portion of a coated abrasive article according to an embodiment.

[0019] FIG. 6 includes a cross-sectional illustration of a portion of a coated abrasive article according to an embodiment.

[0020] FIG. 7 includes a top-down illustration of a portion of a coated abrasive article according to an embodiment.

[0021] FIG. 8A includes a top-down illustration of a portion of a coated abrasive article according to an embodiment.

[0022] FIG. 8B includes a perspective view illustration of a portion of a coated abrasive article according to an embodiment.

[0023] FIG. 9 includes a perspective view illustration of a portion of a coated abrasive article according to an embodiment.

[0024] FIG. 10 includes a top view illustration of a portion of an abrasive article in accordance with an embodiment.

[0025] FIG. 11 includes images representative of portions of a coated abrasive according to an embodiment and used to analyze the orientation of shaped abrasive particles on the backing.

[0026] FIGs. 12A-12C include illustrations of a shaped abrasive particle according to an embodiment.

[0027] FIG. 12D includes a top-down image of a shaped abrasive particle with a line of sectioning for measurement of draft angle according to an embodiment.

[0028] FIG. 12E includes a cross-sectional image of a shaped abrasive particle for measurement of a draft angle according to an embodiment.

[0029] FIG. 12F includes a cross-sectional image of a shaped abrasive particle for measurement of a draft angle according to an embodiment.

[0030] FIGs. 13- 16 include images of shaped abrasive particles according to embodiments.

[0031] FIG. 17 includes an image of a conventional shaped abrasive particle.

[0032] FIG. 18 includes a plot of median force per area for various samples of shaped abrasive particles.

[0033] FIGs. 19-20 include images of shaped abrasive particles according to an embodiment.

[0034] FIG. 21 includes a plot of median force per area for various samples of shaped abrasive particles.

[0035] FIG. 22 includes a plot of specific grinding energy per cumulative material removed for various samples of shaped abrasive particles.

[0036] FIG. 23 includes a plot of specific grinding energy per cumulative material removed for various samples of shaped abrasive particles.

DETAILED DESCRIPTION

[0037] The following is directed to abrasive articles including shaped abrasive particles. The methods herein may be utilized in forming shaped abrasive particles and using abrasive articles incorporating shaped abrasive particles. The shaped abrasive particles may be utilized in various applications, including for example coated abrasives, bonded abrasives, free abrasives, and a combination thereof. Various other uses may be derived for the shaped abrasive particles.

[0038] SHAPED ABRASIVE PARTICLES

[0039] Various methods may be utilized to obtain shaped abrasive particles. The particles may be obtained from a commercial source or fabricated. Some suitable processes used to fabricate the shaped abrasive particles can include, but is not limited to, depositing, printing (e.g., screen-printing), molding, pressing, casting, sectioning, cutting, dicing, punching, pressing, drying, curing, coating, extruding, rolling, and a combination thereof.

[0040] Shaped abrasive particles are formed such that each particle has substantially the same arrangement of surfaces and edges relative to each other for shaped abrasive particles having the same two-dimensional and three-dimensional shapes. As such, shaped abrasive particles can have a high shape fidelity and consistency in the arrangement of the surfaces and edges relative to other shaped abrasive particles of the group having the same two-dimensional and three-dimensional shape. By contrast, non-shaped abrasive particles can be formed through different process and have different shape attributes. For example, non-shaped abrasive particles are typically formed by a comminution process, wherein a mass of material is formed and then crushed and sieved to obtain abrasive particles of a certain size. However, a non-shaped abrasive particle will have a generally random arrangement of the surfaces and edges, and generally will lack any recognizable two-dimensional or three dimensional shape in the arrangement of the surfaces and edges around the body. Moreover, non-shaped abrasive particles of the same group or batch generally lack a consistent shape with respect to each other, such that the surfaces and edges are randomly arranged when compared to each other. Therefore, non-shaped grains or crushed grains have a significantly lower shape fidelity compared to shaped abrasive particles.

[0041] FIG. 1 includes an illustration of a system 150 for forming a shaped abrasive particle in accordance with one, non-limiting embodiment. The process of forming shaped abrasive particles can be initiated by forming a mixture 101 including a ceramic material and a liquid. In particular, the mixture 101 can be a gel formed of a ceramic powder material and a liquid. In accordance with an embodiment, the gel can be formed of the ceramic powder material as an integrated network of discrete particles.

[0042] The mixture 101 may contain a certain content of solid material, liquid material, and additives such that it has suitable rheological characteristics for use with the process detailed herein. That is, in certain instances, the mixture can have a certain viscosity, and more particularly, suitable rheological characteristics that form a dimensionally stable phase of material that can be formed through the process as noted herein. A dimensionally stable phase of material is a material that can be formed to have a particular shape and substantially maintain the shape for at least a portion of the processing subsequent to forming. In certain instances, the shape may be retained throughout subsequent processing, such that the shape initially provided in the forming process is present in the finally-formed object. It will be appreciated that in some instances, the mixture 101 may not be a shape-stable material, and the process may rely upon solidification and stabilization of the mixture 101 by further processing, such as drying.

[0043] The mixture 101 can be formed to have a particular content of solid material, such as the ceramic powder material. For example, in one embodiment, the mixture 101 can have a solids content of at least about 25 wt%, such as at least about 35 wt%, or even at least about 38 wt% for the total weight of the mixture 101. Still, in at least one non-limiting embodiment, the solids content of the mixture 101 can be not greater than about 75 wt%, such as not greater than about 70 wt%, not greater than about 65 wt%, not greater than about 55 wt%, not greater than about 45 wt%, or not greater than about 42 wt%. It will be appreciated that the content of the solids materials in the mixture 101 can be within a range between any of the minimum and maximum percentages noted above.

[0044] According to one embodiment, the ceramic powder material can include an oxide, a nitride, a carbide, a boride, an oxycarbide, an oxynitride, and a combination thereof. In particular instances, the ceramic material can include alumina. More specifically, the ceramic material may include a boehmite material, which may be a precursor of alpha alumina. The term “boehmite” is generally used herein to denote alumina hydrates including mineral boehmite, typically being $Al_2O_3{\bullet}H_2O$ and having a water content on the order of 15%, as well as pseudoboehmite, having a water content higher than 15%, such as 20-38% by weight. It is noted that boehmite (including pseudoboehmite) has a particular and identifiable crystal structure, and therefore a unique X-ray diffraction pattern. As such, boehmite is distinguished from other aluminous materials including other hydrated aluminas such as ATH (aluminum trihydroxide), a common precursor material used herein for the fabrication of boehmite particulate materials.

[0045] Furthermore, the mixture 101 can be formed to have a particular content of liquid material. Some suitable liquids may include water. In accordance with one embodiment, the mixture 101 can be formed to have a liquid content less than the solids content of the mixture 101. In more particular instances, the mixture 101 can have a liquid content of at least about 25 wt% for the total weight of the mixture 101. In other instances, the amount of liquid within the mixture 101 can be greater, such as at least about 35 wt%, at least about 45 wt%, at least about 50 wt%, or even at least about 58 wt%. Still, in at least one non-limiting embodiment, the liquid content of the mixture can be not greater than about 75 wt%, such as not greater than about 70 wt%, not greater than about 65 wt%, not greater than about 62 wt%, or even not greater than about 60 wt%. It will be appreciated that the content of the liquid in the mixture 101 can be within a range between any of the minimum and maximum percentages noted above.

[0046] Furthermore, to facilitate processing and forming shaped abrasive particles according to embodiments herein, the mixture 101 can have a particular storage modulus. For example, the mixture 101 can have a storage modulus of at least about $1x10^4$ Pa, such as at least about $4x10^4$ Pa, or even at least about $5x10^4$ Pa. However, in at least one non-limiting embodiment, the mixture 101 may have a storage modulus of not greater than about $1x10^7$ Pa , such as not greater than about $2x10^6$ Pa. It will be appreciated that the storage modulus of the mixture 101 can be within a range between any of the minimum and maximum values noted above.

[0047] The storage modulus can be measured via a parallel plate system using ARES or AR-G2 rotational rheometers, with Peltier plate temperature control systems. For testing, the mixture 101 can be extruded within a gap between two plates that are set to be approximately 8 mm apart from each other. After extruding the gel into the gap, the distance between the two plates defining the gap is reduced to 2 mm until the mixture 101 completely fills the gap between the plates. After wiping away excess mixture, the gap is decreased by 0.1 mm and the test is initiated. The test is an oscillation strain sweep test conducted with instrument settings of a strain range between 0.01% to 100%, at 6.28 rad/s (1 Hz), using 25-mm parallel plate and recording 10 points per decade. Within 1 hour after the test completes, the gap is lowered again by 0.1 mm and the test is repeated. The test can be repeated at least 6 times. The first test may differ from the second and third tests. Only the results from the second and third tests for each specimen should be reported.

[0048] Furthermore, to facilitate processing and forming shaped abrasive particles according to embodiments herein, the mixture 101 can have a particular viscosity. For example, the mixture 101 can have a viscosity of at least about $2x10^3$ Pa s, such as at least about $3x10^3$ Pa s, at least about $4x10^3$ Pa s, at least about $5x10^3$ Pa s, at least about $6x10^3$ Pa s, at least about $8x10^3$ Pa s, at least about $10x10^3$ Pa s, at least about $20x10^3$ Pa s, at least about $30x10^3$ Pa s, at least about $40x10^3$ Pa s, at least about $50x10^3$ Pa s, at least about $60x10^3$ Pa s, or at least about $65x10^3$ Pa s. In at least one non-limiting embodiment, the mixture 101 may have a viscosity of not greater than about $100x10^3$ Pa s, such as not greater than about $95x10^3$ Pa s, not greater than about $90x10^3$ Pa s, or even not greater than about $85x10^3$ Pa s. It will be appreciated that the viscosity of the mixture 101 can be within a range between any of the minimum and maximum values noted above. The viscosity can be measured in the same manner as the storage modulus as described above.

[0049] Moreover, the mixture 101 can be formed to have a particular content of organic materials including, for example, organic additives that can be distinct from the liquid to facilitate processing and formation of shaped abrasive particles according to the embodiments herein. Some suitable organic additives can include stabilizers, binders such as fructose, sucrose, lactose, glucose, UV curable resins, and the like.

[0050] Notably, the embodiments herein may utilize a mixture 101 that can be distinct from slurries used in conventional forming operations. For example, the content of organic materials within the mixture 101 and, in particular, any of the organic additives noted above, may be a minor amount as compared to other components within the mixture 101. In at least one embodiment, the mixture 101 can be formed to have not greater than about 30 wt% organic material for the total weight of the mixture 101. In other instances, the amount of organic materials may be less, such as not greater than about 15 wt%, not greater than about 10 wt%, or even not greater than about 5 wt%. Still, in at least one non-limiting embodiment, the amount of organic materials within the mixture 101 can be at least about 0.01 wt%, such as at least about 0.5 wt% for the total weight of the mixture 101. It will be appreciated that the amount of organic materials in the mixture 101 can be within a range between any of the minimum and maximum values noted above.

[0051] Moreover, the mixture 101 can be formed to have a particular content of acid or base, distinct from the liquid content, to facilitate processing and formation of shaped abrasive particles according to the embodiments herein. Some suitable acids or bases can include nitric acid, sulfuric acid, citric acid, chloric acid, tartaric acid, phosphoric acid, ammonium nitrate, and ammonium citrate. According to one particular embodiment in which a nitric acid additive is used, the mixture 101 can have a pH of less than about 5, and more particularly, can have a pH within a range between about 2 and about 4.

[0052] The system 150 of FIG. 1, can include a die 103. As illustrated, the mixture 101 can be provided within the interior of the die 103 and configured to be extruded through a die opening 105 positioned at one end of the die 103. As further illustrated, extruding can include applying a force 180 on the mixture 101 to facilitate extruding the mixture 101 through the die opening 105. During extrusion within an application zone 183, a tool 151 can be in direct contact with a portion of the die 103 and facilitate extrusion of the mixture 101 into the tool cavities 152. The tool 151 can be in the form of a screen, such as illustrated in FIG. 1, wherein the cavities 152 extend through the entire thickness of the tool 151. Still, it will be appreciated that the tool 151 may be formed such that the cavities 152 extend for a portion of the entire thickness of the tool 151 and have a bottom surface, such that the volume of space configured to hold and shape the mixture 101 is defined by a bottom surface and side surfaces.

[0053] The tool 151 may be formed of a metal material, including for example, a metal alloy, such as stainless steel. In other instances, the tool 151 may be formed of an organic material, such as a polymer.

[0054] In accordance with an embodiment, a particular pressure may be utilized during extrusion. For example, the pressure can be at least about 10 kPa, such as at least about 500 kPa. Still, in at least one non-limiting embodiment, the pressure utilized during extrusion can be not greater than about 4 MPa. It will be appreciated that the pressure used to extrude the mixture 101 can be within a range between any of the minimum and maximum values noted above. In particular instances, the consistency of the pressure delivered by a piston 199 may facilitate improved processing and formation of shaped abrasive particles. Notably, controlled delivery of consistent pressure across the mixture 101 and across the width of the die 103 can facilitate improved processing control and improved dimensional characteristics of the shaped abrasive particles.

[0055] Prior to depositing the mixture 101 in the tool cavities 152, a mold release agent can be applied to the surfaces of the tool cavities 152, which may facilitate removal of precursor shaped abrasive particles from the tool cavities 152 after further processing. Such a process can be optional and may not necessarily be used to conduct the molding process. A suitable exemplary mold release agent can include an organic material, such as one or more polymers (e.g., PTFE). In other instances, an oil (synthetic or organic) may be applied as a mold release agent to the surfaces of the tool cavities 152. One suitable oil may be peanut oil. The mold release agent may be applied using any suitable manner, including but not limited to, depositing, spraying, printing, brushing, coating, and the like.

[0056] The mixture 101 may be deposited within the tool cavities 152, which may be shaped in any suitable manner to form shaped abrasive particles having shapes corresponding to the shape of the tool cavities 152.

[0057] Referring briefly to FIG. 2, a portion of the tool 151 is illustrated. As shown, the tool 151 can include the tool cavities 152, and more particularly, a plurality of tool cavities 152 extending into the volume of the tool 151. In accordance with an embodiment, the tool cavities 152 can have a two-dimensional shape as viewed in a plane defined by the length (l) and width (w) of the tool 151. The two-dimensional shape can include various shapes such as, for example, polygons, ellipsoids, numerals, Greek alphabet letters, Latin alphabet letters, Russian alphabet characters, complex shapes including a combination of polygonal shapes, and a combination thereof. In particular instances, the tool cavities 152 may have two-dimensional polygonal shapes such as a rectangle, a quadrilateral, a pentagon, a hexagon, a heptagon, an octagon, a nonagon, a decagon, and a combination thereof. Notably, as will be appreciated in further reference to the shaped abrasive particles of the embodiments herein, the tool cavities 152 may utilize various other shapes.

[0058] While the tool 151 of FIG. 2 is illustrated as having tool cavities 152 oriented in a particular manner relative to each other, it will be appreciated that various other orientations may be utilized. In accordance with one embodiment, each of the tool cavities 152 can have substantially the same orientation relative to each other, and substantially the same orientation relative to the surface of the screen. For example, each of the tool cavities 152 can have a first edge 154 defining a first plane 155 for a first row 156 of the tool cavities 152 extending laterally across a lateral axis 158 of the tool 151. The first plane 155 can extend in a direction substantially orthogonal to a longitudinal axis 157 of the tool 151. However, it will be appreciated, that in other instances, the tool cavities 152 need not necessarily have the same orientation relative to each other.

[0059] Moreover, the first row 156 of tool cavities 152 can be oriented relative to a direction of translation to facilitate particular processing and controlled formation of shaped abrasive particles. For example, the tool cavities 152 can be arranged on the tool 151 such that the first plane 155 of the first row 156 defines an angle relative to the direction of translation 171. As illustrated, the first plane 155 can define an angle that is substantially orthogonal to the direction of translation 171. Still, it will be appreciated that in one embodiment, the tool cavities 152 can be arranged on the tool 151 such that the first plane 155 of the first row 156 defines a different angle with respect to the direction of translation, including for example, an acute angle or an obtuse angle. Still, it will be appreciated that the tool cavities 152 may not necessarily be arranged in rows. The tool cavities 152 may be arranged in various particular ordered distributions with respect to each other on the tool 151, such as in the form of a two-dimensional pattern. Alternatively, the openings may be disposed in a random manner on the tool 151.

[0060] Referring again to FIG. 1, during operation of the system 150, the tool 151 can be translated in a direction 153 to facilitate a continuous molding operation. As will be appreciated, the tool 151 may be in the form of a continuous belt, which can be translated over rollers to facilitate continuous processing. In some embodiments, the tool 151 can be translated while extruding the mixture 101 through the die opening 105. As illustrated in the system 150, the mixture 101 may be extruded in a direction 191. The direction of translation 153 of the tool 151 can be angled relative to the direction of extrusion 191 of the mixture 101. While the angle between the direction of translation 153 and the direction of extrusion 191 is illustrated as substantially orthogonal in the system 100, other angles are contemplated, including for example, an acute angle or an obtuse angle. After the mixture 101 is extruded through the die opening 105, the mixture 101 and tool 151 may be translated under a knife edge 107 attached to a surface of the die 103. The knife edge 107 may define a region at the front of the die 103 that facilitates displacement of the mixture 101 into the tool cavities 152 of the tool 151.

[0061] In the molding process, the mixture 101 may undergo significant drying while contained in the tool cavity 152. Therefore, shaping may be primarily attributed to substantial drying and solidification of the mixture 101 in the tool cavities 152 to shape the mixture 101. In certain instances, the shaped abrasive particles formed according to the molding process may exhibit shapes more closely replicating the features of the mold cavity compared to other processes, including for example, screen printing processes. However, it should be noted that certain beneficial shape characteristics may be more readily achieved through screen printing processes.

[0062] After applying the mold release agent, the mixture 101 can be deposited within the mold cavities and dried. Drying may include removal of a particular content of certain materials from the mixture 101, including volatiles, such as water or organic materials. In accordance with an embodiment, the drying process can be conducted at a drying temperature of not greater than about 300°C, such as not greater than about 250°C, not greater than about 200°C, not greater than about 150°C, not greater than about 100°C, not greater than about 80°C, not greater than about 60°C, not greater than about 40°C, or even not greater than about 30°C. Still, in one non-limiting embodiment, the drying process may be conducted at a drying temperature of at least about -20°C, such as at least about -10°C at least about 0°C at least about 5°C at least about 10°C, or even at least about 20°C. It will be appreciated that the drying temperature may be within a range between any of the minimum and maximum temperatures noted above.

[0063] In certain instances, drying may be conducted for a particular duration to facilitate the formation of shaped abrasive particles according to embodiments herein. For example, drying can be conducted for a duration of at least about 1 minute, such as at least about 2 minutes, at least about 4 minutes, at least about 6 minutes, at least about 8 minutes, at least about 10 minutes, at least about 30 minutes, at least about 1 hour, at least about 2 hours, at least about 4 hours, at least about 8 hours, at least about 12 hours, at least about 15 hours, at least about 18 hours, at least about 24 hours. In still other instances, the process of drying may be not greater than about 30 hours, such as not greater than about 24 hours, not greater than about 20 hours, not greater than about 15 hours, not greater than about 12 hours, not greater than about 10 hours, not greater than about 8 hours, not greater than about 6 hours, not greater than about 4 hours. It will be appreciated that the duration of drying can be within a range between any of the minimum and maximum values noted above.

[0064] Additionally, drying may be conducted at a particular relative humidity to facilitate formation of shaped abrasive particles according to the embodiments herein. For example, drying may be conducted at a relative humidity of at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, such as at least about 62%, at least about 64%, at least about 66%, at least about 68%, at least about 70%, at least about 72%, at least about 74%, at least about 76%, at least about 78%, or even at least about 80%. In still other non-limiting embodiments, drying may be conducted at a relative humidity of not greater than about 90%, such as not greater than about 88%, not greater than about 86%, not greater than about 84%, not greater than about 82%, not greater than about 80%, not greater than about 78%, not greater than about 76%, not greater than about 74%, not greater than about 72%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, or even not greater than about 25%. It will be appreciated that the relative humidity utilized during drying can be within a range between any of the minimum and maximum percentages noted above.

[0065] After completing the drying process, the mixture 101 can be released from the tool cavities 152 to produce precursor shaped abrasive particles. Notably, before the mixture 101 is removed from the tool cavities 152 or after the mixture 101 is removed and the precursor shaped abrasive particles are formed, one or more post-forming processes may be completed. Such processes can include surface shaping, curing, reacting, radiating, planarizing, calcining, sintering, sieving, doping, and a combination thereof. For example, in one optional process, the mixture 101 or precursor shaped abrasive particles may be translated through an optional shaping zone, wherein at least one exterior surface of the mixture or precursor shaped abrasive particles may be shaped. In still another embodiment, the mixture 101 as contained in the mold cavities or the precursor shaped abrasive particles may be translated through an optional application zone, wherein a dopant material can be applied. In particular instances, the process of applying a dopant material can include selective placement of the dopant material on at least one exterior surface of the mixture 101 or precursor shaped abrasive particles. In an optional process, the mixture 101 may be treated with one or more acid or base materials. Treatment may occur post-calcination and may affect a distribution of dopant material within the shaped abrasive particle. In a particular instance, treatment with one or more acid or base materials may facilitate increased performance of the shaped abrasive particle. The process of applying a dopant can include doping (i.e., additives or a provision of additives to the gel prior to calcination). In alternative instances, an impregnation process may be used instead of doping, where impregnation utilizes an additive introduced to the precursor particles after calcination. Utilization of doping or impregnation may affect distribution of the dopant material within the final shaped abrasive particle which may also facilitate increased performance of the shaped abrasive particle.

[0066] The dopant material may be applied utilizing various methods including for example, spraying, dipping, depositing, impregnating, transferring, punching, cutting, pressing, crushing, and any combination thereof. In accordance with an embodiment, applying a dopant material can include the application of a particular material, such as a precursor. In certain instances, the precursor can be a salt, such as a metal salt, that includes a dopant material to be incorporated into the finally-formed shaped abrasive particles. For example, the metal salt can include an element or compound that is the precursor to the dopant material. It will be appreciated that the salt material may be in liquid form, such as in a dispersion comprising the salt and liquid carrier. The salt may include nitrogen, and more particularly, can include a nitrate. In other embodiments, the salt can be a chloride, sulfate, phosphate, and a combination thereof. In one embodiment, the salt can include a metal nitrate, and more particularly, consist essentially of a metal nitrate. In one embodiment, the dopant material can include an element or compound such as an alkali element, alkaline earth element, rare earth element, hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, or a combination thereof. In one particular embodiment, the dopant material includes an element or compound including an element such as lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, niobium, hafnium, zirconium, tantalum, molybdenum, vanadium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof.

[0067] In an embodiment, the dopant material may include a first dopant material and a second dopant material, where the second dopant material includes an element or compound different than the first dopant material. A ratio of the first dopant material to the second dopant material can be in a range of about 1:4 and about 1:1, such as in a range of about 1:3 and 1:1.5, or even in a range of about 1:2.5 and 1:2. In one particular instance, the ratio of the first dopant material to the second dopant material can be approximately 1:2.

[0068] In a particular instance, the first dopant material can be in a range of at least about 0.5 wt% and not greater than 5 wt% based on a total weight of the body and the second dopant material can be in a range of at least about 1 wt% and no greater than about 5 wt% based on the total weight of the body.

[0069] In a particular embodiment, the first dopant material can include a magnesium-containing species and the second dopant material can include a zirconium-containing species.

[0070] In a particular instance, a wt% ratio of the zirconium-containing species to the magnesium-containing species is at least about 1:4, or at least about 1:3.5, or at least about 1:3, or at least about 1:2.5, or at least 1:2, or at least about 1:1.5, or at least about 1:1. In another particular instance, the wt% ratio of the zirconium-containing species to the magnesium-containing species is not greater than about 1:1.

[0071] The molding process may further include a sintering process. For certain embodiments herein, sintering can be conducted after removing the mixture from the tool cavities 152 and forming the precursor shaped abrasive particles. Sintering of the precursor shaped abrasive particles 123 may be utilized to densify the particles, which are generally in a green state. In a particular instance, the sintering process can facilitate the formation of a high-temperature phase of the ceramic material. For example, in one embodiment, the precursor shaped abrasive particles may be sintered such that a high-temperature phase of alumina, such as alpha alumina, is formed. In one instance, a shaped abrasive particle can comprise at least about 90 wt% alpha alumina for the total weight of the particle. In other instances, the content of alpha alumina may be greater such that the shaped abrasive particle may consist essentially of alpha alumina.

[0072] The body of the finally-formed shaped abrasive particles can have particular two-dimensional shapes. For example, the body can have a two-dimensional shape, as viewed in a plane defined by the length and width of the body, and can have a shape including a polygonal shape, ellipsoidal shape, a numeral, a Greek alphabet character, a Latin alphabet character, a Russian alphabet character, a complex shape utilizing a combination of polygonal shapes and a combination thereof. Particular polygonal shapes include rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, nonagonal, decagonal, and any combination thereof. In another instance, the finally-formed shaped abrasive particles can have a body having a two-dimensional shape such as an irregular quadrilateral, an irregular rectangle, an irregular trapezoid, an irregular pentagon, an irregular hexagon, an irregular heptagon, an irregular octagon, an irregular nonagon, an irregular decagon, and a combination thereof. An irregular polygonal shape is one where at least one of the sides defining the polygonal shape is different in dimension (e.g., length) with respect to another side. As illustrated in other embodiments herein, the two-dimensional shape of certain shaped abrasive particles can have a particular number of exterior points or external corners. For example, the body of the shaped abrasive particles can have a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a two-dimensional shape having at least 4 exterior points (e.g., a quadrilateral), at least 5 exterior points (e.g, a pentagon), at least 6 exterior points (e.g., a hexagon), at least 7 exterior points (e.g., a heptagon), at least 8 exterior points (e.g., an octagon), at least 9 exterior points (e.g., a nonagon), and the like.

[0073] FIG. 3 includes a cross-sectional illustration of a shaped abrasive particle to illustrate certain features of shaped abrasive particles of the embodiments herein. . It will be appreciated that such a cross-sectional view can be applied to any of the exemplary shaped abrasive particles of the embodiments to determine one or more shape aspects or dimensional characteristics as described herein. The body of the shaped abrasive particle can include an upper major surface 303 (i.e., a first major surface) and a bottom major surface 304 (i.e., a second major surface) opposite the upper major surface 303. The upper surface 303 and the bottom surface 304 can be separated from each other by a side surface 314.

[0074] In certain instances, the shaped abrasive particles of the embodiments herein, can have an average difference in height, which is a measure of the difference between hc and hm. Notably, the dimension of Lmiddle can be a length defining a distance between a height at a corner (hc) and a height at a midpoint edge (hm) opposite the corner. Moreover, the body 301 can have an interior height (hi), which can be the smallest dimension of height of the body 301 as measured along a dimension between any corner and opposite midpoint edge on the body 301. For convention herein, average difference in height will be generally identified as hc-hm, however it is defined as an absolute value of the difference. Therefore, it will be appreciated that average difference in height may be calculated as hm-hc when the height of the body 301 at the side surface 314 is greater than the height at the corner 313. More particularly, the average difference in height can be calculated based upon a plurality of shaped abrasive particles from a suitable sample size. The heights hc and hm of the particles can be measured using a STIL (Sciences et Techniques Industrielles de la Lumiere - France) Micro Measure 3D Surface Profilometer (white light (LED) chromatic aberration technique) and the average difference in height can be calculated based on the average values of hc and hm from the sample.

[0075] As illustrated in FIG. 3, in one particular embodiment, the body 301 of the shaped abrasive particle 300 may have an average difference in height at different locations at the body 301. The body 301 can have an average difference in height, which can be the absolute value of [hc-hm] between the first corner height (hc) and the second midpoint height (hm) that is quite low, such that the particle is relative flat, having an average difference in height that is not greater than about 300 microns, such as not greater than about 250 microns, not greater than about 220 microns, not greater than about 180 microns, not greater than about 150 microns, not greater than about 100 microns, not greater than about 50 microns, or even not greater than about 20 microns.

[0076] The body of the shaped abrasive particles herein can include a width (w) that is the longest dimension of the body and extending along a side. The shaped abrasive particles can include a length that extends through a midpoint of the body and bisecting the body (i.e., Lmiddle). The body can further include a height (h), which may be a dimension of the body extending in a direction perpendicular to the length and width in a direction defined by a side surface of the body 301. In specific instances, the width can be greater than or equal to the length, the length can be greater than or equal to the height, and the width can be greater than or equal to the height.

[0077] In particular instances, the body 301 can be formed to have a primary aspect ratio, which is a ratio expressed as width:length, having a value of at least 1:1. In other instances, the body 301 can be formed such that the primary aspect ratio (w:l) is at least about 1.5:1, such as at least about 2:1, at least about 4:1, or even at least about 5:1. Still, in other instances, the abrasive particle 300 can be formed such that the body 301 has a primary aspect ratio that is not greater than about 10:1, such as not greater than 9:1, not greater than about 8:1, or even not greater than about 5:1. It will be appreciated that the body 301 can have a primary aspect ratio within a range between any of the ratios noted above. Furthermore, it will be appreciated that reference herein to a height can be reference to the maximum height measurable of the abrasive particle 300.

[0078] In addition to the primary aspect ratio, the abrasive particle 300 can be formed such that the body 301 comprises a secondary aspect ratio, which can be defined as a ratio of length:height, wherein the height is an interior median height (Mhi). In certain instances, the secondary aspect ratio can be at least about 1:1, such as at least about 2:1, at least about 4:1, or even at least about 5:1. Still, in other instances, the abrasive particle 300 can be formed such that the body 301 has a secondary aspect ratio that is not greater than about 1:3, such as not greater than 1:2, or even not greater than about 1:1. It will be appreciated that the body 301 can have a secondary aspect ratio within a range between any of the ratios noted above, such as within a range between about 5:1 and about 1:1.

[0079] In accordance with another embodiment, the abrasive particle 300 can be formed such that the body 301 comprises a tertiary aspect ratio, defined by the ratio width:height, wherein the height is an interior median height (Mhi). The tertiary aspect ratio of the body 301 can be can be at least about 1:1, such as at least about 2:1, at least about 4:1, at least about 5:1, or even at least about 6:1. Still, in other instances, the abrasive particle 300 can be formed such that the body 301 has a tertiary aspect ratio that is not greater than about 3:1, such as not greater than 2:1, or even not greater than about 1:1. It will be appreciated that the body 301 can have a tertiary aspect ratio within a range between any of the ratios noted above, such as within a range between about 6:1 and about 1:1.

[0080] According to one embodiment, the body 301 of the shaped abrasive particle 300 can have particular dimensions, which may facilitate improved performance. For example, in one instance, the body 301 can have an interior height (hi), which can be the smallest dimension of height of the body 301 as measured along a dimension between any corner and opposite midpoint edge on the body 301. In particular instances, the interior height (hi) may be the smallest dimension of height (i.e., measure between the bottom surface 304 and the upper surface 305) of the body 301 for three measurements taken between each of the exteriorcorners and the opposite midpoint edges. The interior height (hi) of the body 301 of a shaped abrasive particle 300 is illustrated in FIG. 3. According to one embodiment, the interior height (hi) can be at least about 20% of the width (w). The height (hi) may be measured by sectioning or mounting and grinding the shaped abrasive particle 300 and viewing in a manner sufficient (e.g., light microscope or SEM) to determine the smallest height (hi) within the interior of the body 301. In one particular embodiment, the height (hi) can be at least about 22% of the width, such as at least about 25%, at least about 30%, or even at least about 33%, of the width of the body 301. For one non-limiting embodiment, the height (hi) of the body 301 can be not greater than about 80% of the width of the body 301, such as not greater than about 76%, not greater than about 73%, not greater than about 70%, not greater than about 68% of the width, not greater than about 56% of the width, not greater than about 48% of the width, or even not greater than about 40% of the width. It will be appreciated that the height (hi) of the body 301 can be within a range between any of the above noted minimum and maximum percentages.

[0081] A batch of shaped abrasive particles can be fabricated where the median interior height value (Mhi) can be controlled, which may facilitate improved performance. In particular, the median internal height (hi) of a batch can be related to a median width of the shaped abrasive particles of the batch in the same manner as described above. Notably, the median interior height (Mhi) can be at least about 20% of the width, such as at least about 22%, at least about 25%, at least about 30%, or even at least about 33% of the median width of the shaped abrasive particles of the batch. For one non-limiting embodiment, the median interior height (Mhi) of the body 301 can be not greater than about 80%, such as not greater than about 76%, not greater than about 73%, not greater than about 70%, not greater than about 68% of the width, not greater than about 56% of the width, not greater than about 48% of the width, or even not greater than about 40% of the median width of the body 301. It will be appreciated that the median interior height (Mhi) of the body 301 can be within a range between any of the above noted minimum and maximum percentages.

[0082] Furthermore, the batch of shaped abrasive particles may exhibit improved dimensional uniformity as measured by the standard deviation of a dimensional characteristic from a suitable sample size. According to one embodiment, the shaped abrasive particles can have an interior height variation (Vhi), which can be calculated as the standard deviation of interior height (hi) for a suitable sample size of particles from a batch. According to one embodiment, the interior height variation can be not greater than about 60 microns, such as not greater than about 58 microns, not greater than about 56 microns, or even not greater than about 54 microns. In one non-limiting embodiment, the interior height variation (Vhi) can be at least about 2 microns. It will be appreciated that the interior height variation of the body can be within a range between any of the above noted minimum and maximum values.

[0083] For another embodiment, the body 301 of the shaped abrasive particle 300 can have a height, which may be an interior height (hi), of at least about 70 microns. More particularly, the height may be at least about 80 microns, such as at least about 90 microns, at least about 100 microns, at least about 110 microns, at least about 120 microns, at least about 150 microns, at least about 175 microns, at least about 200 microns, at least about 225 microns, at least about 250 microns, at least about 275 microns, or even at least about 300 microns. In still one non-limiting embodiment, the height of the body 301 can be not greater than about 3 mm, such as not greater than about 2 mm, not greater than about 1.5 mm, not greater than about 1 mm, or even not greater than about 800 microns, not greater than about 600 microns, not greater than about 500 microns, not greater than about 475 microns, not greater than about 450 microns, not greater than about 425 microns, not greater than about 400 microns, not greater than about 375 microns, not greater than about 350 microns, not greater than about 325 microns, not greater than about 300 microns, not greater than about 275 microns, or even not greater than about 250 microns. It will be appreciated that the height of the body 301 can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median interior height (Mhi) value for a batch of shaped abrasive particles.

[0084] For certain embodiments herein, the body 301 of the shaped abrasive particle 300 can have particular dimensions, including for example, a width>length, a length>height, and a width>height. More particularly, the body 301 of the shaped abrasive particle 300 can have a width (w) of at least about 200 microns, such as at least about 250 microns, at least about 300 microns, at least about 350 microns, at least about 400 microns, at least about 450 microns, at least about 500 microns, at least about 550 microns, at least about 600 microns, at least about 700 microns, at least about 800 microns, or even at least about 900 microns. In one non-limiting instance, the body 301 can have a width of not greater than about 4 mm, such as not greater than about 3 mm, not greater than about 2.5 mm, or even not greater than about 2 mm. It will be appreciated that the width of the body 301 can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median width (Mw) for a batch of shaped abrasive particles.

[0085] The body 301 of the shaped abrasive particle 300 can have particular dimensions, including for example, a length (Lmiddle or Lp) of at least about 0.4 mm, such as at least about 0.6 mm, at least about 0.8 mm, or even at least about 0.9 mm. Still, for at least one non-limiting embodiment, the body 301 can have a length of not greater than about 4 mm, such as not greater than about 3 mm, not greater than about 2.5 mm, or even not greater than about 2 mm. It will be appreciated that the length of the body 301 can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median length (Ml), which may be more particularly a median middle length (MLmiddle) or median profile length (MLp), for a batch of shaped abrasive particles.

[0086] The shaped abrasive particle 300 can have a body 301 having a particular amount of dishing, wherein the dishing value (d) can be defined as a ratio between an average height of the body 301 at the exterior corners (Ahc) as compared to the smallest dimension of height of the body 301 at the interior (hi). The average height of the body 301 at the corners (Ahc) can be calculated by measuring the height of the body 301 at all corners and averaging the values, and may be distinct from a single value of height at one corner (hc). The average height of the body 301 at the corners or at the interior can be measured using a STIL (Sciences et Techniques Industrielles de la Lumiere - France) Micro Measure 3D Surface Profilometer (white light (LED) chromatic aberration technique). Alternatively, the dishing may be based upon a median height of the particles at the corner (Mhc) calculated from a suitable sampling of particles from a batch. Likewise, the interior height (hi) can be a median interior height (Mhi) derived from a suitable sampling of shaped abrasive particles from a batch. According to one embodiment, the dishing value (d) can be not greater than about 2, such as not greater than about 1.9, not greater than about 1.8, not greater than about 1.7, not greater than about 1.6, not greater than about 1.5, or even not greater than about 1.2. Still, in at least one non-limiting embodiment, the dishing value (d) can be at least about 0.9, such as at least about 1.0. It will be appreciated that the dishing ratio can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above dishing values can be representative of a median dishing value (Md) for a batch of shaped abrasive particles.

[0087] The shaped abrasive particles of the embodiments herein, including for example, the body 301 of the particle of FIG. 3 can have a bottom surface 304 defining a bottom area (A_b). In particular instances, the bottom surface 304 can be the largest surface of the body 301. The bottom major surface 304 can have a surface area defined as the bottom area (A_b) that is different than the surface area of the upper major surface 303. In one particular embodiment, the bottom major surface 304 can have a surface area defined as the bottom area (A_b) that is different than the surface area of the upper major surface 303. In another embodiment, the bottom major surface 304 can have a surface area defined as the bottom area (A_b) that is less than the surface area of the upper major surface 303.

[0088] Additionally, the body 301 can have a cross-sectional midpoint area (A_m) defining an area of a plane perpendicular to the bottom area (A_b) and extending through a midpoint 381 of the particle 300. In certain instances, the body 301 can have an area ratio of bottom area to midpoint area (A_b/A_m) of not greater than about 6. In more particular instances, the area ratio can be not greater than about 5.5, such as not greater than about 5, not greater than about 4.5, not greater than about 4, not greater than about 3.5, or even not greater than about 3. Still, in one non-limiting embodiment, the area ratio may be at least about 1.1, such as at least about 1.3, or even at least about 1.8. It will be appreciated that the area ratio can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above area ratios can be representative of a median area ratio for a batch of shaped abrasive particles.

[0089] Furthermore the shaped abrasive particles of the embodiments herein including, for example, the particle of FIG. 3, can have a normalized height difference of not greater than about 0.3. The normalized height difference can be defined by the absolute value of the equation [(hc-hm)/(hi)]. In other embodiments, the normalized height difference can be not greater than about 0.26, such as not greater than about 0.22, or even not greater than about 0.19. Still, in one particular embodiment, the normalized height difference can be at least about 0.04, such as at least about 0.05, or even at least about 0.06. It will be appreciated that the normalized height difference can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above normalized height values can be representative of a median normalized height value for a batch of shaped abrasive particles.

[0090] The shaped abrasive particle 300 can be formed such that the body 301 includes a crystalline material, and more particularly, a polycrystalline material. Notably, the polycrystalline material can include abrasive grains. In one embodiment, the body 301 can be essentially free of an organic material, including for example, a binder. More particularly, the body 301 can consist essentially of a polycrystalline material.

[0091] In one aspect, the body 301 of the shaped abrasive particle 300 can be an agglomerate including a plurality of abrasive particles, grit, and/or grains bonded to each other to form the body 301 of the abrasive particle 300. Suitable abrasive grains can include nitrides, oxides, carbides, borides, oxynitrides, oxyborides, diamond, and a combination thereof. In particular instances, the abrasive grains can include an oxide compound or complex, such as aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof. In one particular instance, the abrasive particle 300 is formed such that the abrasive grains forming the body 301 include alumina, and more particularly, may consist essentially of alumina. Moreover, in particular instances, the shaped abrasive particle 300 can be formed from a seeded sol-gel.

[0092] The abrasive grains (i.e., crystallites) contained within the body 301 may have an average grain size that is generally not greater than about 100 microns. In other embodiments, the average grain size can be less, such as not greater than about 80 microns, not greater than about 50 microns, not greater than about 30 microns, not greater than about 20 microns, not greater than about 10 microns, or even not greater than about 1 micron, not greater than about 0.9 microns, not greater than about 0.8 microns, not greater than about 0.7 microns, or even not greater than about 0.6 microns. Still, the average grain size of the abrasive grains contained within the body 301 can be at least about 0.01 microns, such as at least about 0.05 microns, at least about 0.06 microns, at least about 0.07 microns, at least about 0.08 microns, at least about 0.09 microns, at least about 0.1 microns, at least about 0.12 microns, at least about 0.15 microns, at least about 0.17 microns, at least about 0.2 microns, or even at least about 0.5 microns. It will be appreciated that the abrasive grains can have an average grain size within a range between any of the minimum and maximum values noted above.

[0093] In accordance with certain embodiments, the abrasive particle 300 can be a composite article including at least two different types of grains within the body 301. It will be appreciated that different types of grains are grains having different compositions with regard to each other. For example, the body 301 can be formed such that is includes at least two different types of grains, wherein the two different types of grains can be nitrides, oxides, carbides, borides, oxynitrides, oxyborides, diamond, and a combination thereof.

[0094] In accordance with an embodiment, the abrasive particle 300 can have an average particle size, as measured by the largest dimension measurable on the body 301, of at least about 100 microns. In fact, the abrasive particle 300 can have an average particle size of at least about 150 microns, such as at least about 200 microns, at least about 300 microns, at least about 400 microns, at least about 500 microns, at least about 600 microns, at least about 700 microns, at least about 800 microns, or even at least about 900 microns. Still, the abrasive particle 300 can have an average particle size that is not greater than about 5 mm, such as not greater than about 3 mm, not greater than about 2 mm, or even not greater than about 1.5 mm. It will be appreciated that the abrasive particle 300 can have an average particle size within a range between any of the minimum and maximum values noted above.

[0095] The shaped abrasive particles of the embodiments herein can have a percent flashing that may facilitate improved performance. Notably, the flashing defines an area of the particle as viewed along one side, such as illustrated in FIG. 4, wherein the flashing extends from a side surface of the body 301 within the boxes 402 and 403. The flashing can represent tapered regions proximate to the upper surface 303 and bottom surface 304 of the body 301. The flashing can be measured as the percentage of area of the body 301 along the side surface contained within a box extending between an innermost point of the side surface (e.g., 421) and an outermost point (e.g., 422) on the side surface of the body 301. In one particular instance, the body 301 can have a particular content of flashing, which can be the percentage of area of the body 301 contained within the boxes 402 and 403 compared to the total area of the body 301 contained within boxes 402, 403, and 404. According to one embodiment, the percent flashing (f) of the body 301 can be at least about 1%. In another embodiment, the percent flashing can be greater, such as at least about 2%, at least about 3%, at least about 5%, at least about 8%, at least about 10%, at least about 12%, such as at least about 15%, at least about 18%, or even at least about 20%. Still, in a non-limiting embodiment, the percent flashing of the body 301 can be controlled and may be not greater than about 45%, such as not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 18%, not greater than about 15%, not greater than about 12%, not greater than about 10%, not greater than about 8%, not greater than about 6%, or even not greater than about 4%. It will be appreciated that the percent flashing of the body 301 can be within a range between any of the above minimum and maximum percentages. Moreover, it will be appreciated that the above flashing percentages can be representative of an average flashing percentage or a median flashing percentage for a batch of shaped abrasive particles.

[0096] The percent flashing can be measured by mounting the shaped abrasive particle 300 on its side and viewing the body 301 at the side to generate a black and white image, such as illustrated in FIG. 4. A suitable program for such includes ImageJ software. The percentage flashing can be calculated by determining the area of the body 301 in the boxes 402 and 403 compared to the total area of the body 301 as viewed at the side (total shaded area), including the area in the center 404 and within the boxes. Such a procedure can be completed for a suitable sampling of particles to generate average, median, and/or and standard deviation values.

[0097] FIGs. 12A-and 12C include illustrations of a shaped abrasive particle according to an embodiment. The body of the shaped abrasive particles of the embodiments herein can have a particular relationship between at least three grain features, including tip sharpness, strength, and Shape Index. Without wishing to be tied to a particular theory, based on empirical studies it appears that a particular interrelationship between certain grain features may exist, and by controlling the interrelationship of these grain features, the self-sharpening behavior of the shaped abrasive particle may be modified, and improved, which may facilitate the formation of abrasive articles having improved performance in terms of efficiency and life.

[0098] FIG. 12A includes a perspective view illustration of a shaped abrasive particle according to an embodiment. FIGs. 12B and 12C include a top view illustrations of the shaped abrasive particle of FIG. 12A. As illustrated, the shaped abrasive particle 1200 can include a body 1201 having an upper major surface 1203 (i.e., a first major surface) and a bottom major surface 1204 (i.e., a second major surface) opposite the upper major surface 1203. The upper surface 1203 and the bottom surface 1204 can be separated from each other by at least one side surface 1205, which may include one or more discrete side surface portions, including for example, discrete side surface portions 1206, 1207, and 1208. The discrete side surface portions 1206-1208 may be joined to each other at edges, including but not limited to, edges 1209, 1210, and 1211. The edges 1209, 1210, and 1211 can extend between external corners of the upper major surface and the bottom major surface 1204. For example, the edge 1210 can extend between an external corner 1213 of the upper major surface 1203 and an external corner 1214 of the bottom major surface 1204.

[0099] As illustrated, the body 1201 of the shaped abrasive particle 1200 can have a generally polygonal shape as viewed in a plane parallel to the upper surface 1203, and more particularly, the body 1201 can have a substantially triangular (e.g., equilateral triangular) two-dimensional shape as viewed in the plane of the width (W) and length (L or Lmiddle) of the body (i.e., the top view as shown in FIG. 12B and FIG. 12C). In particular, the body 1201 can have a length (L or Lmiddle) as shown in FIG. 12A, which may be measured as the dimension extending from the external corner 1216 through a midpoint 1281 of the body 1201 to a midpoint at the opposite edge 1217 of the body 1201. Moreover, the body 1201 can have a width (W), which is the measure of the longest dimension of the body 1201 along a discrete side surface portion (e.g., 1206) of the side surface 1205. The height of the body may be generally the distance between the upper major surface 1203 and the bottom major surface 1204. As described in embodiments herein, the height may vary in dimension at different locations of the body 1201, such as at the corners versus at the interior of the body 1201.

[00100] Moreover, as described in other embodiments herein, the body 1201 can have a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height. In particular instances, the body 1201 can be formed to have a primary aspect ratio, which is a ratio expressed as width:length, having the values described in embodiments herein. Likewise, the body 1201 can have a secondary aspect ratio (i.e., length:height) and a tertiary aspect ratio (i.e., width:height) that may be the same as described in other embodiments herein.

[00101] According to one embodiment, the body 1201 of the shaped abrasive particle 1200 may be formed using any of the processes described herein. Notably, the body 1201 may be formed such that it has a particular interrelationship of at least three grain features, including a predetermined strength, a predetermined tip sharpness, and a predetermined Shape Index. The tip sharpness of a shaped abrasive particle, which may be an average tip sharpness, may be measured by determining the largest radius of a best fit circle on an external corner of the body 1201. For example, turning to FIG. 12B, a top view of the upper major surface 1203 of the body 1201 is provided. For the external corner 1216, a best fit circle is overlaid on the image of the body 1201 of the shaped abrasive particle 1201, and the radius of the best fit circle relative to the curvature of the external corner 1216 defines the value of tip sharpness for the external corner 1216. The measurement may be recreated for each external corner of the body 1201 to determine the average individual tip sharpness for a single shaped abrasive

particle. Moreover, the measurement may be recreated on a suitable sample size of shaped abrasive particles of a batch of shaped abrasive particles to derive the average batch tip sharpness. Any suitable computer program, such as ImageJ may be used in conjunction with an image (e.g., SEM image or light microscope image) of suitable magnification to accurately measure the best fit circle and the tip sharpness.

[00102] The shaped abrasive particles of the embodiments herein may have a particular tip sharpness that facilitates formation of shaped abrasive particles with a particular sharpness, strength and Shape Index factor (i.e., 3SF). For example, the body 1201 of a shaped abrasive particle, according to an embodiment, can have a tip sharpness within a range between not greater than about 80 microns and at least about 1 micron. Moreover, in certain instances, the body 1201 can have a tip sharpness of not greater than about 78 microns, such as not greater than about 76 microns, not greater than about 74 microns, not greater than about 72 microns, not greater than about 70 microns, not greater than about 68 microns, not greater than about 66 microns, not greater than about 64 microns, not greater than about 62 microns, not greater than about 60 microns, not greater than about 58 microns, not greater than about 56 microns, not greater than about 54 microns, not greater than about 52 microns, not greater than about 50 microns, not greater than about 48 microns, not greater than about 46 microns, not greater than about 44 microns, not greater than about 42 microns, not greater than about 40 microns, not greater than about 38 microns, not greater than about 36 microns, not greater than about 34 microns, not greater than about 32 microns, not greater than about 30 microns, not greater than about 38 microns, not greater than about 36 microns, not greater than about 34 microns, not greater than about 32 microns, not greater than about 30 microns, not greater than about 28 microns, not greater than about 26 microns, not greater than about 24 microns, not greater than about 22 microns, not greater than about 20 microns, not greater than about 18 microns, not greater than about 16 microns, not greater than about 14 microns, not greater than about 12 microns, not greater than about 10 microns. In yet another non-limiting embodiment, the body 1201 can have a tip sharpness of at least about 2 microns, such as at least about 4 microns, at least about 6 microns, at least about 8 microns, at least about 10 microns, at least about 12 microns, at least about 14 microns, at least about 16 microns, at least about 18 microns, at least about 20 microns, at least about 22 microns, at least about 24 microns, at least about 26 microns, at least about 28 microns, at least about 30 microns, at least about 32 microns, at least about 34 microns, at least about 36 microns, at least about 38 microns, at least about 40 microns, at least about 42 microns, at least about 44 microns, at least about 46

microns, at least about 48 microns, at least about 50 microns, at least about 52 microns, at least about 54 microns, at least about 56 microns, at least about 58 microns, at least about 60 microns, at least about 62 microns, at least about 64 microns, at least about 66 microns, at least about 68 microns, at least about 70 microns. It will be appreciated that the body 1201 can have a tip sharpness within a range between any of the minimum and maximum values noted above.

[00103] As noted herein, another grain feature is the Shape Index. The Shape Index of the body 1201 can be described as a value of an outer radius of a best-fit outer circle superimposed on the body 1201 as viewed in two dimensions of the plane of length and width (i.e., the upper major surface 1203 or the bottom major surface 1204) compared to an inner radius of the largest-best fit inner circle fitting entirely within the body 1201 as viewed in the two dimensions of the plane of length and width of the body 1201. For example, turning to FIG. 12C, a top view of the body 1201 of the shaped abrasive particle 1200 is provided with two circles superimposed on the illustration to demonstrate the calculation of Shape Index. A first, outer circle is superimposed on the body 1201, which is a best-fit outer circle representing the smallest circle that can fit the entire perimeter of the body of the shaped abrasive particle within its boundaries. The outer circle has a radius (Ro). For shapes such as that illustrated in FIG. 12C, the outer circle may intersect the perimeter of the body at each of the three corners of the equilateral triangle two-dimensional shape. However, it will be appreciated that for certain irregular or complex shapes, the body may not fit uniformly within the circle such that each of the corners intersect the circle at equal intervals, but a best-fit, outer circle may be formed regardless. Any suitable computer program, such as ImageJ may be used in conjunction with an image of suitable magnification (e.g., SEM image or light microscope image) to create the outer circle and measure the radius (Ro).

[00104] A second, inner circle can be superimposed on the image of a shaped abrasive grain, as illustrated in FIG. 12C, and is a best fit circle representing the largest circle that can be placed entirely within the perimeter of the two dimensional shape of the body 1201 as viewed in the plane of the length and width of the body 1201. The inner circle can have a radius (Ri). It will be appreciated that for certain irregular or complex shapes, the inner circle may not fit uniformly within the body such that the perimeter of the circle contacts portions of the body at equal intervals, such as shown for the regular pentagon of FIG. 12C. However, a best-fit, inner circle may be formed regardless. Any suitable computer program, such as ImageJ may

be used in conjunction with an image of suitable magnification (e.g., SEM image or light microscope image) to create the inner circle and measure the radius (Ri).

[00105] The Shape Index can be calculated by dividing the outer radius by the inner radius (i.e., Shape Index = Ri/Ro). For example, the body 1201 of the shaped abrasive particle 1200 of FIGs. 12A-12C has a Shape Index within a range between at least about 0.48 and not greater than about 0.52.

[00106] The shaped abrasive particles of the embodiments herein may have a particular Shape Index that facilitates formation of shaped abrasive particles with a particular 3SF. For example, the body may have a Shape Index within a range between at least about 0.48 and not greater than about 0.52. More particularly, in one non-limiting embodiment, the body of the shaped abrasive particle can have a Shape Index of approximately 0.5.

[00107] Moreover, as noted herein, the body may be formed to have a particular strength. The strength of the body may be measured via Hertzian indentation. In this method the abrasive grains are glued on a slotted aluminum SEM sample mounting stub. The slots are approximately 250 µm deep and wide enough to accommodate the grains in a row. The grains are polished in an automatic polisher using a series of diamond pastes, with the finest paste of 1 µm to achieve a final mirror finish. At the final step, the polished grains are flat and flush with the aluminum surface. The height of the polished grains is therefore approximately 250 µm. The metal stub is fixed in a metal support holder and indented with a steel spherical indenter using an MTS universal test frame. The crosshead speed during the test is 2 µm/s. The steel ball used as the indenter is 3.2 mm in diameter. The maximum indentation load is the same for all grains, and the load at first fracture is determined from the load displacement curve as a load drop. After indentation, the grains are imaged optically to document the existence of the cracks and the crack pattern.

[00108] Using the first load drop as the pop-in load of the first ring crack, the Hertzian strength can be calculated. The Hertzian stress field is well defined and axisymmetrical. The stresses are compressive right under the indenter and tensile outside a region defined by the radius of the contact area. At low loads, the field is completely elastic. For a sphere of radius R and an applied normal load of P, the solutions for the stress field are readily found following the original Hertzian assumption that the contact is friction free.

[00109] The radius of the contact area a is given by:

[00110] $$a^3 = \frac{3PR}{4E^*} \qquad (1)$$

[00111] Where $$E^{*} = \left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right)^{-1} \qquad (2)$$

[00112] and E* is a combination of the Elastic modulus E and the Poisson's ratio ν for the indenter and sample material, respectively.

[00113] The maximum contact pressure is given by:

[00114] $$p_0 = \left(\frac{3P}{2\pi a^2} \right) = \left(\frac{6PE^{*2}}{\pi^3 R^2} \right)^{\frac{1}{3}} \qquad (3)$$

[00115] The maximum shear stress is given by (assuming $\nu = 0.3$): $\tau_1 = 0.31$, p_0, at R = 0 and z = 0.48 a

[00116] The Hertzian strength is the maximum tensile stress at the onset of cracking and is calculated according to: $\sigma_r = 1/3\ (1-2\ \nu)\ p_0$, at R= a and z=0.

[00117] Using the first load drop as the load P in Eq. (3) the maximum tensile stress is calculated following the equation above, which is the value of the Hertzian strength for the specimen. In total, between 20 and 30 individual shaped abrasive particle samples are tested for each grit type, and a range of Hertzian fracture stress is obtained. Following Weibull analysis procedures (as outlined in ASTM C1239), a Weibull probability plot is generated, and the Weibull Characteristic strength (the scale value) and the Weibull modulus (the shape parameter) are calculated for the distribution using the maximum likelihood procedure.

[00118] The shaped abrasive particles of the embodiments herein may have a particular strength that facilitates formation of shaped abrasive particles with a particular 3SF. For example, the body of shaped abrasive particles of the embodiments herein can have a strength within a range between not greater than about 600 MPa and at least about 350 MPa. This may be achieved using any of the compositions described in the embodiments herein, including but not limited to, a single ceramic composition, a doped ceramic composition, or a composite composition. According to a particular embodiment, the strength of the body 1201 may be not greater than about 590 MPa, such as not greater than about 580 MPa, not greater than about 570 MPa, not greater than about 560 MPa, not greater than about 550 MPa, not greater than about 540 MPa, not greater than about 530 MPa, not greater than about 520 MPa, not greater than about 510 MPa, not greater than about 500 MPa, not greater than about 490 MPa, not greater than about 480 MPa, not greater than about 470 MPa, not greater than about 460 MPa, not greater than about 450 MPa, not greater than about 440 MPa, not greater than about 430 MPa, not greater than about 420 MPa, not greater than about 410 MPa, not

greater than about 400 MPa, not greater than about 390 MPa, not greater than about 380 MPa, not greater than about 370 MPa, or even not greater than about 360 MPa. In yet another non-limiting embodiment, the strength of the body 1201 may be at least about 360 MPa, at least about 370 MPa, at least about 380 MPa, at least about 390 MPa, at least about 400 MPa, at least about 410 MPa, at least about 420 MPa, at least about 430 MPa, at least about 440 MPa, at least about 450 MPa, at least about 460 MPa, at least about 470 MPa, at least about 480 MPa, at least about 490 MPa, or even at least about 500 MPa. It will be appreciated that the strength of the body may be within a range between any of the minimum and maximum values noted above.

[00119] According to one aspect, empirical studies of shaped abrasive particles have indicated that by controlling particular grain features of tip sharpness, strength, and Shape Index with respect to each other, the grinding behavior (e.g., the self-sharpening behavior) of the shaped abrasive particles can be modified. Notably, the forming process can be undertaken in a manner such that the interrelationship of the grain features of tip sharpness, Shape Index, and strength of the body are selected and controlled in a predetermined manner to influence the grinding performance (e.g., self-sharpening behavior) of the shaped abrasive particle. For example, in one embodiment, the method of forming the shaped abrasive particle can include selecting a material having a predetermined strength and forming the body of the shaped abrasive particle with a predetermined tip sharpness and predetermined Shape Index based upon the predetermined strength. That is, a material for forming the shaped abrasive particle may first be selected, such that the body will have a predetermined strength, and thereafter the grain features of a predetermined tip sharpness and predetermined Shape Index may be selected and controlled based on the predetermined strength, such that the shaped abrasive particle may have improved performance over conventional shaped abrasive particles.

[00120] In still another embodiment, the method of forming the shaped abrasive particle can include selecting a material having a predetermined Shape Index and forming the body of the shaped abrasive particle with a predetermined tip sharpness and predetermined strength based upon the predetermined Shape Index. That is, a shape of the body of the shaped abrasive particle may first be selected, and thereafter the grain features of a predetermined tip sharpness and predetermined strength of the body may be selected and controlled based on the predetermined Shape Index, such that the shaped abrasive particle can have improved performance over conventional shaped abrasive particles.

[00121] In yet another approach, a method of forming a shaped abrasive particle can include selecting a predetermined tip sharpness of a body of the shaped abrasive particle. After predetermining the tip sharpness of the body, the Shape Index and a strength of the body may be selected and controlled based upon the predetermined tip sharpness. Such a process may facilitate formation of a shaped abrasive particle having improved performance over conventional shaped abrasive particles.

[00122] In yet another embodiment, the method of forming the shaped abrasive particle can include selecting a material having a predetermined height, which may be an average height, an interior height, or height at an edge or tip of the body, and forming the body of the shaped abrasive particle with a predetermined tip sharpness, predetermined strength, and predetermined Shape Index based on the predetermined height. That is, a height of the body of the shaped abrasive particle may first be selected, and thereafter the grain features of a predetermined tip sharpness, strength, and Shape Index of the body may be selected and controlled based on the predetermined height, such that the shaped abrasive particle can have improved performance over conventional shaped abrasive particles.

[00123] Moreover, through empirical studies, it has been found that the performance of the shaped abrasive particle may be initially predicted by the interrelationship of the tip sharpness, strength, and Shape Index, which may be evaluated based upon a sharpness-shape-strength factor (3SF) according to the formula: $3SF = [(S*R*B^2)/2500]$, wherein "S" represents the strength of the body (in MPa), R represents the tip sharpness of the body (in microns), and "B" represents the Shape Index of the body. The 3SF formula is intended to provide an initial prediction of the effectiveness of grinding behavior of the particle based upon the interrelationship of the grain features. It should be noted that other factors, such as aspects of the abrasive article in which the shaped abrasive particle is integrated, may influence the behavior of the particle.

[00124] In accordance with one embodiment, the body of a shaped abrasive particle may have a particular 3SF value within a range between at least about 0.7 and not greater than about 1.7. In at least one embodiment, the body can have a 3SF of at least about 0.72, such as at least about 0.75, at least about 0.78, at least about 0.8, at least about 0.82, at least about 0.85, at least about 0.88, at least about 0.90, at least about 0.92, at least about 0.95, or even at least about 0.98. In yet another instance, the body can have a 3SF of not greater than about 1.68, such as not greater than about 1.65, not greater than about 1.62, not greater than about 1.6, not greater than about 1.58, not greater than about 1.55, not greater than about 1.52, not

greater than about 1.5, not greater than about 1.48, not greater than about 1.45, not greater than about 1.42, not greater than about 1.4, not greater than about 1.38, not greater than about 1.35, not greater than about 1.32, not greater than about 1.3, not greater than about 1.28, not greater than about 1.25, not greater than about 1.22, not greater than about 1.2, not greater than about 1.18, not greater than about 1.15, not greater than about 1.12, not greater than about 1.1. It will be appreciated that the body can have a 3SF within a range between any of the minimum and maximum values noted above.

[00125] The shaped abrasive particles of the embodiments herein having the particular grain features and 3SF can have any of the other features of the embodiments described herein. In one aspect, the body 1201 of the shaped abrasive particle can have a particular composition. For example, the body 1201 may include a ceramic material, such as a polycrystalline ceramic material, and more particularly an oxide. The oxide may include, for example alumina. In certain instances, the body may include a majority content of alumina, such as at least about 95 wt% alumina for the total weight of the body, or such as at least about 95.1 wt%, at least about 95.2 wt%, at least about 95.3 wt%, at least about 95.4 wt%, at least about 95.5 wt%, at least about 95.6 wt%, at least about 95.7 wt%, at least about 95.8 wt%, at least about 95.9 wt%, at least about 96 wt%, at least about 96.1 wt%, at least about 96.2 wt%, at least about 96.3 wt%, at least about 96.4 wt%, at least about 96.5 wt%, at least about 96.6 wt%, at least about 96.7 wt%, at least about 96.8 wt%, at least about 96.9 wt%, at least about 97 wt%, at least about 97.1 wt%, at least about 97.2 wt%, at least about 975.3 wt%, at least about 97.4 wt%, or even at least about 97.5 wt% alumina for the total weight of the body. Still, in another non-limiting embodiment, the body 1201 may include a content of alumina not greater than about 99.5 wt%, such as not greater than about 99.4 wt%, not greater than about 99.3wt%, not greater than about 99.2 wt%, not greater than about 99.1 wt%, not greater than about 99 wt%, not greater than about 98.9 wt%, not greater than about 98.8 wt%, not greater than about 98.7wt%, not greater than about 98.6 wt%, not greater than about 98.5 wt%, not greater than about 98.4 wt%, not greater than about 98.3 wt%, not greater than about 98.2 wt%, not greater than about 98.1wt%, not greater than about 98 wt%, not greater than about 97.9 wt%, not greater than about 97.8 wt%, not greater than about 97.7 wt%, not greater than about 97.6 wt%, or even not greater than about 97.5wt% alumina for the total weight of the body 1201. It will be appreciated that the body 1201 may include a content of alumina within a range between any of the minimum and maximum values noted above.

[00126] As noted in embodiments herein, the body of the shaped abrasive particles maybe formed to include certain additives. The additives can be non-organic species, including but not limited to an oxide. In one particular instance, the additive may be a dopant material, which may be present in a particular minor amount sufficient to affect the microstructure of the material, but present in a greater content than a trace amount or less. The dopant material may include an element selected from the group of hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof. In still a more particular embodiment, the dopant material may include magnesium, and may be a magnesium-containing species, including but not limited to, magnesium oxide (MgO).

[00127] According to one embodiment, the magnesium-containing species can be a compound including magnesium and at least one other element. In at least one embodiment, the magnesium-containing compound can include an oxide compound, such that the magnesium-containing species includes magnesium and oxygen. In yet another embodiment, the magnesium-containing species can include aluminum, and more particularly may be a magnesium aluminate species. For example, in certain instances, the magnesium-containing species can be a spinel material. The spinel material may be stoichiometric or non-stoichiometric spinel.

[00128] The magnesium-containing species may be a distinct phase of material formed in the body as compared to another primary phase, including for example, an alumina phase. The magnesium-containing species may be preferentially disposed at the grain boundaries of the primary phase (e.g., alumina grains). In still other instances, the magnesium-containing species may be primarily and uniformly dispersed throughout the volume of the grains of the primary phase.

[00129] The magnesium-containing species may be a strength-altering material. For example, in at least one embodiment, the addition of the magnesium-containing species can be configured to reduce the strength of the body compared to a body that does not include the magnesium-containing species.

[00130] Certain compositions of the shaped abrasive particles of the embodiments can include a particular content of magnesium oxide. For example, the body 1201 may include a content of a magnesium-containing species of at least about 0.5 wt%, such as at least about 0.6 wt%, at least about 0.7 wt%, at least about 0.8 wt%, at least about 0.9 wt%, at least about 1 wt%, at

least about 1.1 wt%, at least about 1.2 wt%, at least about 1.3 wt%, at least about 1.4 wt%, at least about 1.5 wt%, at least about 1.6 wt%, at least about 1.7 wt%, at least about 1.8 wt%, at least about 1.9 wt%, at least about 2 wt%, at least about 2.1 wt%, at least about 2.2 wt%, at least about 2.3 wt%, at least about 2.4 wt%, or even at least about 2.5 wt% for the total weight of the body 1201. In still another non-limiting embodiment, the body 1201 may include a content of a magnesium-containing species of not greater than about 5 wt%, such as not greater than about 4.9 wt%, not greater than about 4.8 wt%, not greater than about 4.7wt%, not greater than about 4.6 wt%, not greater than about 4.5 wt%, not greater than about 4.4 wt%, not greater than about 4.3 wt%, not greater than about 4.2wt%, not greater than about 4.1 wt%, not greater than about 4 wt%, not greater than about 3.9 wt%, not greater than about 3.8 wt%, not greater than about 3.7wt%, not greater than about 3.6 wt%, not greater than about 3.5 wt%, not greater than about 3.4 wt%, not greater than about 3.3 wt%, not greater than about 3.2wt%, not greater than about 3.1 wt%, not greater than about 3 wt%, not greater than about 2.9 wt%, not greater than about 2.8 wt%, not greater than about 2.7wt%, not greater than about 2.6 wt%, or even not greater than about 2.5 wt%. It will be appreciated that the content of a magnesium-containing species within the body may be within a range between any of the minimum and maximum values noted above. Furthermore, in at least one embodiment, the body 1201 may consist essentially of alumina (Al_2O_3) and the magnesium-containing species.

[00131] In a particular instance, the shaped abrasive particles of the embodiments herein can have a particular draft angle at the intersection of the smallest major surface and the side surface, which may be indicative of a particular aspect of forming and/or may facilitate improved performance of the abrasive particle. In one particular instance, the shaped abrasive particles herein can have a average draft angle, α, which can be an average measure of draft angle for a statistically relevant and random sample size of shaped abrasive particles (e.g., at least 20 particles). In a particular instance, the average draft angle can be not greater than 95°, such as not greater than 94° or no greater than 93° or not greater than 92° or not greater than 91° or even not greater than 90°. In at least one non-limiting embodiment, the shaped abrasive particles of the embodiments herein can have an average draft angle of at least 80° such as at least 82° or at least 84° or at least 85° or at least 86° or at least 87°. It will be appreciated that the shaped abrasive particles of the embodiments herein can have an average draft angle within a range including any of the minimum and maximum values noted above, including but not limited to, within a range of at least 80° and not greater than 95° or

within a range including at least 80° and not greater than 94° or within a range including at least 82° and not greater than93° or within a range including at least 84° and not greater than 93°.

[00132] The draft angle can be measured by cutting the shaped abrasive particle in half at an approximately 90° angle with respect to the major surface and at a perpendicular angle to one of the side surfaces, such as shown by the dotted line in FIG. 12D. As best as possible, the sectioning line should extend perpendicular to the side surface and through the midpoint of a major surface of the particle. The portion of the shaped abrasive particle is then mounted and viewed via SEM in a manner that is similar to that provided in FIG. 12E. A suitable program for such includes ImageJ software. Using the image of the body, the smallest major surface is determined by identifying the largest major surface and selecting the surface opposite thereof. Certain shaped abrasive particles may have a generally square cross-sectional shape. To identify the smallest major surface, the largest major surface must first be determined. The smallest major surface is that surface opposite the largest major surface. The imaging software, such as ImageJ may be utilized to assist with the determination of the smallest major surface. Using a suitable image processing software (e.g., ImageJ) draw a straight line along both of the major surfaces between the corners adjoining the major surfaces and the sidewall as provided by the lines below in FIG. 12E. Using the image analysis software, measure the line that longer. The shorter of the two lines is presumed to be the smaller of the two major surfaces. In the case provided in FIG. 12E, the line on the right of the image is shorter and the draft angle should be measured at the corner identified at the upper right-hand corner, which is also illustrated in FIG. 12F.

[00133] To measure the draft angle, lines can be drawn along the smallest major surface and the side surface to form an intersecting angle as provided in FIG. 12F. The lines are drawn taking into consideration the shape of the surfaces as a whole and ignoring imperfections or other non-representative surface undulations at the corner of the particle (e.g., cracks or chips due to mounting procedures, etc.). Moreover, the line representing the smaller major surface is drawn to represent the portion of the major surface that connects the sidewall at the draft angle. The draft angle (i.e., the angle of the body as measured at the intersection) is determined by the interior angle formed at the intersection of the lines.

[00134] Moreover, as noted herein the body of a shaped abrasive particle of any of the embodiments herein may be formed of a polycrystalline material including grains, which may be made of materials such as nitrides, oxides, carbides, borides, oxynitrides, diamond, and a

combination thereof. Further, the body 1201 can be essentially free of an organic material, essentially free of rare earth elements, and essentially free of iron. The body 1201 may be essentially free of nitrides, essentially free of chlorides, essentially free of nitrides, or essentially free of oxynitrides. Being essentially free is understood to mean that the body is formed in a manner to exclude such materials, but the body may not necessarily be completely free of such materials as they may be present in trace amounts or less.

[00135] In addition to the foregoing grain features and 3SF values of the embodiments herein, in certain instances, the height of the grain may be an additional or alternative grain feature that may be interrelated to certain grain features described herein. In particular, the height of the grain may be controlled with respect to any of the grain features (e.g., strength and tip sharpness) to facilitate improved grinding performance of the shaped abrasive particles and abrasive articles using such shaped abrasive particles. Notably, the shaped abrasive particles of the embodiments herein can have a particular height, which may be interrelated to certain grain features, such that stresses encountered during grinding may be distributed throughout the body in a manner to facilitate improved self-sharpening behavior. According to one embodiment, the body of the shaped abrasive particles can have a height (h) within a range between about 70 microns and about 500 microns, such as within a range between about 175 microns to about 350 microns, such as between about 175 microns and about 300 microns, or even within a range between about 200 microns and about 300 microns.

[00136] A FIXED ABRASIVE ARTICLE

[00137] After forming or sourcing the shaped abrasive particles, the particles can be combined with other materials to form a fixed abrasive article. In a fixed abrasive, the shaped abrasive particles can be coupled to a matrix or substrate and used for material removal operations. Some suitable exemplary fixed abrasive articles can include bonded abrasive articles wherein the shaped abrasive particles are contained in a three dimensional matrix of bond material. In other instances, the fixed abrasive article may be a coated abrasive article, wherein the shaped abrasive particles may be dispersed in a single-layer overlying a backing and bonded to the backing using one or more adhesive layers.

[00138] FIG. 5A includes an illustration of a bonded abrasive article incorporating the abrasive particulate material in accordance with an embodiment. As illustrated, the bonded abrasive 590 can include a bond material 591, abrasive particulate material 592 contained in the bond material, and porosity 598 within the bond material 591. In particular instances, the bond material 591 can include an organic material, inorganic material, and a combination

thereof. Suitable organic materials can include polymers, such as epoxies, resins, thermosets, thermoplastics, polyimides, polyamides, and a combination thereof. Certain suitable inorganic materials can include metals, metal alloys, vitreous phase materials, crystalline phase materials, ceramics, and a combination thereof.

[00139] In some instances, the abrasive particulate material 592 of the bonded abrasive 590 can include shaped abrasive particles 593, 594, 595, and 596. In particular instances, the shaped abrasive particles 593, 594, 595, and 596 can be different types of particles, which can differ from each other in composition, two-dimensional shape, three-dimensional shape, size, and a combination thereof as described in the embodiments herein. Alternatively, the bonded abrasive article can include a single type of shaped abrasive particle.

[00140] The bonded abrasive 590 can include a type of abrasive particulate material 597 representing diluent abrasive particles, which can differ from the shaped abrasive particles 593, 594, 595, and 596 in composition, two-dimensional shape, three-dimensional shape, size, and a combination thereof.

[00141] The porosity 598 of the bonded abrasive 590 can be open porosity, closed porosity, and a combination thereof. The porosity 598 may be present in a majority amount (vol%) based on the total volume of the body of the bonded abrasive 590. Alternatively, the porosity 598 can be present in a minor amount (vol%) based on the total volume of the body of the bonded abrasive 590. The bond material 591 may be present in a majority amount (vol%) based on the total volume of the body of the bonded abrasive 590. Alternatively, the bond material 591 can be present in a minor amount (vol%) based on the total volume of the body of the bonded abrasive 590. Additionally, abrasive particulate material 592 can be present in a majority amount (vol%) based on the total volume of the body of the bonded abrasive 590. Alternatively, the abrasive particulate material 592 can be present in a minor amount (vol%) based on the total volume of the body of the bonded abrasive 590.

[00142] FIG. 5B includes a cross-sectional illustration of a coated abrasive article in accordance with an embodiment. In particular, the coated abrasive article 500 can include a substrate 501 (e.g., a backing) and at least one adhesive layer overlying a surface of the substrate 501. The adhesive layer can include a make coat 503 and/or a size coat 504. The coated abrasive article 500 can include abrasive particulate material 510, which can include shaped abrasive particles 505 of any of the embodiments herein and a second type of abrasive particulate material 507 in the form of diluent abrasive particles having a random shape, which may not necessarily be shaped abrasive particles. The shaped abrasive particles 505 of

FIG. 5B are illustrated generally for purposes or discussion, and it will be appreciated that the coated abrasive article can include any shaped abrasive particles of the embodiments herein. The make coat 503 can be overlying the surface of the substrate 501 and surrounding at least a portion of the shaped abrasive particles 505 and second type of abrasive particulate material 507. The size coat 504 can be overlying and bonded to the shaped abrasive particles 505 and second type of abrasive particulate material 507and the make coat 503.

[00143] According to one embodiment, the substrate 501 can include an organic material, inorganic material, and a combination thereof. In certain instances, the substrate 501 can include a woven material. However, the substrate 501 may be made of a non-woven material. Particularly suitable substrate materials can include organic materials, including polymers such as polyester, polyurethane, polypropylene, and/or polyimides such as KAPTON from DuPont, and paper. Some suitable inorganic materials can include metals, metal alloys, and particularly, foils of copper, aluminum, steel, and a combination thereof. The backing can include one or more additives selected from the group of catalysts, coupling agents, curants, anti-static agents, suspending agents, anti-loading agents, lubricants, wetting agents, dyes, fillers, viscosity modifiers, dispersants, defoamers, and grinding agents.

[00144] A polymer formulation may be used to form any of a variety of layers of the coated abrasive article 500 such as, for example, a frontfill, a pre-size, the make coat, the size coat, and/or a supersize coat. When used to form the frontfill, the polymer formulation generally includes a polymer resin, fibrillated fibers (preferably in the form of pulp), filler material, and other optional additives. Suitable formulations for some frontfill embodiments can include material such as a phenolic resin, wollastonite filler, defoamer, surfactant, a fibrillated fiber, and a balance of water. Suitable polymeric resin materials include curable resins selected from thermally curable resins including phenolic resins, urea/formaldehyde resins, phenolic/latex resins, as well as combinations of such resins. Other suitable polymeric resin materials may also include radiation curable resins, such as those resins curable using electron beam, UV radiation, or visible light, such as epoxy resins, acrylated oligomers of acrylated epoxy resins, polyester resins, acrylated urethanes and polyester acrylates and acrylated monomers including monoacrylated, multiacrylated monomers. The formulation can also comprise a nonreactive thermoplastic resin binder which can enhance the self-sharpening characteristics of the deposited abrasive particles by enhancing the erodability. Examples of such thermoplastic resin include polypropylene glycol, polyethylene glycol, and polyoxypropylene-polyoxyethene block copolymer, etc. Use of a frontfill on the substrate

501 can improve the uniformity of the surface, for suitable application of the make coat 503 and improved application and orientation of shaped abrasive particles 505 in a predetermined orientation.

[00145] The make coat 503 can be applied to the surface of the substrate 501 in a single process, or alternatively, the abrasive particulate material 510 can be combined with a make coat 503 material and applied as a mixture to the surface of the substrate 501. Suitable materials of the make coat 503 can include organic materials, particularly polymeric materials, including for example, polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and mixtures thereof. In one embodiment, the make coat 503 can include a polyester resin. The coated substrate can then be heated in order to cure the resin and the abrasive particulate material to the substrate. In general, the coated substrate 501 can be heated to a temperature of between about 100 ºC to less than about 250 ºC during this curing process.

[00146] The abrasive particulate material 510 can include shaped abrasive particles 505 according to embodiments herein. In particular instances, the abrasive particulate material 510 may include different types of shaped abrasive particles 505. The different types of shaped abrasive particles can differ from each other in composition, in two-dimensional shape, in three-dimensional shape, in size, and a combination thereof as described in the embodiments herein. As illustrated, the coated abrasive 500 can include a shaped abrasive particle 505 which may have any of the shapes of the shaped abrasive particles of the embodiments herein.

[00147] The other type of abrasive particles 507 can be diluent particles different than the shaped abrasive particles 505. For example, the diluent particles can differ from the shaped abrasive particles 505 in composition, in two-dimensional shape, in three-dimensional shape, in size, and a combination thereof. For example, the abrasive particles 507 can represent conventional, crushed abrasive grit having random shapes. The abrasive particles 507 may have a median particle size less than the median particle size of the shaped abrasive particles 505.

[00148] After sufficiently forming the make coat 503 with the abrasive particulate material 510, the size coat 504 can be formed to overlie and bond the abrasive particulate material 510 in place. The size coat 504 can include an organic material, may be made essentially of a polymeric material, and notably, can use polyesters, epoxy resins, polyurethanes, polyamides,

polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and mixtures thereof.

[00149] According to one embodiment, the shaped abrasive particles 505 can be oriented in a predetermined orientation relative to each other and/or the substrate 501. While not completely understood, it is thought that one or a combination of dimensional features may be responsible for improved orientation of the shaped abrasive particles 505. According to one embodiment, the shaped abrasive particles 505 can be oriented in a flat orientation relative to the substrate 501, such as that shown in FIG. 5B. In the flat orientation, the bottom surface 304 of the shaped abrasive particles can be closest to a surface of the substrate 501 and the upper surface 303 of the shaped abrasive particles 505 can be directed away from the substrate 501 and configured to conduct initial engagement with a workpiece.

[00150] According to another embodiment, the shaped abrasive particles 505 can be placed on a substrate 501 in a predetermined side orientation, such as that shown in FIG. 6. In particular instances, a majority of the shaped abrasive particles 505 of the total content of shaped abrasive particles 505 on the abrasive article 500 can have a predetermined side orientation. In the side orientation, the bottom surface 304 of the shaped abrasive particles 505 can be spaced away from and angled relative to the surface of the substrate 501. In particular instances, the bottom surface 304 can form an obtuse angle (B) relative to the surface of the substrate 501. Moreover, the upper surface 303 is spaced away and angled relative to the surface of the substrate 501, which in particular instances, may define a generally acute angle (A). In a side orientation, a side surface 305 can be closest to the surface of the substrate 501, and more particularly, may be in direct contact with a surface of the substrate 501.

[00151] For certain other abrasive articles herein, at least about 55% of the plurality of shaped abrasive particles 505 on the abrasive article 500 can be coupled to the backing in a predetermined side orientation. Still, the percentage may be greater, such as at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 77%, at least about 80%, at least about 81%, or even at least about 82%. And for one non-limiting embodiment, an abrasive article 500 may be formed using the shaped abrasive particles 505 herein, wherein not greater than about 99% of the total content of shaped abrasive particles have a predetermined side orientation.

[00152] To determine the percentage of particles in a predetermined orientation, a 2D microfocus x-ray image of the abrasive article 500 is obtained using a CT scan machine run

in the conditions of Table 1 below. The X-ray 2D imaging is conducted on shaped abrasive particles on a backing with Quality Assurance software. A specimen mounting fixture utilizes a plastic frame with a 4” x 4” window and an Ø0.5” solid metallic rod, the top part of which is half flattened with two screws to fix the frame. Prior to imaging, a specimen is clipped over one side of the frame where the screw heads face the incidence direction of the X-rays. Then five regions within the 4” x 4” window area are selected for imaging at 120kV/80μA. Each 2D projection is recorded with the X-ray off-set/gain corrections and at a magnification of 15 times.

[00153] TABLE 1

Voltage (kV)	Current (μA)	Magnification	Field of view per image (mm x mm)	Exposure time
120	80	15X	16.2 x 13.0	500 ms/2.0 fps

[00154]

[00155] The image is then imported and analyzed using the ImageJ program, wherein different orientations are assigned values according to Table 2 below. FIG. 11 includes images representative of portions of a coated abrasive article according to an embodiment, which images can be used to analyze the orientation of shaped abrasive particles on the backing.

[00156] TABLE 2

Cell marker type	Comments
1	Grains on the perimeter of the image, partially exposed – standing up
2	Grains on the perimeter of the image, partially exposed – down
3	Grains on the image, completely exposed – standing vertical
4	Grains on the image, completely exposed – down
5	Grains on the image, completely exposed – standing slanted (between standing vertical and down)

[00157] Three calculations are then performed as provided below in Table 3. After conducting the calculations, the percentage of grains in a particular orientation (e.g., side orientation) per square centimeter can be derived.

[00158] TABLE 3

5) Parameter	Protocol*
% grains up	$((0.5 \times 1) + 3 + 5) \big/ (1 + 2 + 3 + 4 + 5)$
Total # of grains per cm^2	$(1 + 2 + 3 + 4 + 5)$
# of grains up per cm^2	$(\%\, grains\ up\ \times Total\ \#\ of\ grains\ per\ cm^2$

- These are all normalized with respect to the representative area of the image.

+ - A scale factor of 0.5 was applied to account for the fact that they are not completely present in the image.

[00159] Furthermore, the abrasive articles made with the shaped abrasive particles can utilize various contents of the shaped abrasive particles. For example, the abrasive articles can be coated abrasive articles including a single layer of a plurality of shaped abrasive particles in an open-coat configuration or a closed-coat configuration. For example, the plurality of shaped abrasive particles can define an open-coat abrasive article having a coating density of shaped abrasive particles of not greater than about 70 particles/cm^2. In other instances, the open-coat density of shaped abrasive particles per square centimeter of abrasive article may be not greater than about 65 particles/cm^2, such as not greater than about 60 particles/cm^2, not greater than about 55 particles/cm^2, or even not greater than about 50 particles/cm^2. Still, in one non-limiting embodiment, the density of the open-coat abrasive article using the shaped abrasive particle herein can be at least about 5 particles/cm^2, or even at least about 10 particles/cm^2. It will be appreciated that the open-coat density of the coated abrasive article can be within a range between any of the above minimum and maximum values.

[00160] In an alternative embodiment, the plurality of shaped abrasive particles can define a closed-coat abrasive article having a coating density of shaped abrasive particles of at least about 75 particles/cm^2, such as at least about 80 particles/cm^2, at least about 85 particles/cm^2, at least about 90 particles/cm^2, at least about 100 particles/cm^2. Still, in one non-limiting embodiment, the closed-coat density of the coated abrasive article using the shaped abrasive

particle herein can be not greater than about 500 particles/cm^2. It will be appreciated that the closed coat density of the coated abrasive article can be within a range between any of the above minimum and maximum values.

[00161] In certain instances, the abrasive article can have an open-coat density of a coating not greater than about 50% of abrasive particulate material covering the exterior abrasive surface of the article. In other embodiments, the percentage coating of the abrasive particulate material relative to the total area of the abrasive surface can be not greater than about 40%, not greater than about 30%, not greater than about 25%, or even not greater than about 20%. Still, in one non-limiting embodiment, the percentage coating of the abrasive particulate material relative to the total area of the abrasive surface can be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, or even at least about 40%. It will be appreciated that the percent coverage of shaped abrasive particles for the total area of abrasive surface can be within a range between any of the above minimum and maximum values.

[00162] Some abrasive articles may have a particular content of abrasive particles for a length (e.g., ream) of the backing or the substrate 501. For example, in one embodiment, the abrasive article may utilize a normalized weight of shaped abrasive particles of at least about 20 lbs/ream, such as at least about 25 lbs/ ream, or even at least about 30 lbs/ream. Still, in one non-limiting embodiment, the abrasive articles can include a normalized weight of shaped abrasive particles of not greater than about 60 lbs/ream, such as not greater than about 50 lbs/ream, or even not greater than about 45 lbs/ream. It will be appreciated that the abrasive articles of the embodiments herein can utilize a normalized weight of shaped abrasive particles within a range between any of the above minimum and maximum values.

[00163] The plurality of shaped abrasive particles on an abrasive article as described herein can define a first portion of a batch of abrasive particles, and the features described in the embodiments herein can represent features that are present in at least a first portion of a batch of shaped abrasive particles. Moreover, according to an embodiment, control of one or more process parameters as already described herein also can control the prevalence of one or more features of the shaped abrasive particles of the embodiments herein. The provision of one or more features of any shaped abrasive particle of a batch may facilitate alternative or improved deployment of the particles in an abrasive article and may further facilitate improved performance or use of the abrasive article. The batch may also include a second

portion of abrasive particles. The second portion of abrasive particles can include diluent particles.

[00164] In accordance with one aspect of the embodiments herein, a fixed abrasive article can include a blend of abrasive particles. The blend of abrasive particles can include a first type of shaped abrasive particle and a second type of shaped abrasive particle. The first type of shaped abrasive particle can include any features of the shaped abrasive particles of the embodiments herein. The second type of shaped abrasive particle can include any features of the shaped abrasive particles of the embodiments herein.

[00165] The blend of abrasive particles can include a first type of shaped abrasive particle present in a first content (C1), which may be expressed as a percentage (e.g., a weight percent) of the first type of shaped abrasive particles as compared to the total content of particles of the blend. Furthermore, the blend of abrasive particles may include a second content (C2) of the second type of shaped abrasive particles, expressed as a percentage (e.g., a weight percent) of the second type of shaped abrasive particles relative to the total weight of the blend. The first content can be the same as or different from the second content. For example, in certain instances, the blend can be formed such that the first content (C1) can be not greater than about 90% of the total content of the blend. In another embodiment, the first content may be less, such as not greater than about 85%, not greater than about 80%, not greater than about 75%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 15%, not greater than about 10%, or even not greater than about 5%. Still, in one non-limiting embodiment, the first content of the first type of shaped abrasive particles may be present in at least about 1% of the total content of abrasive particles of the blend. In yet other instances, the first content (C1) may be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, or even at least about 95%. It will be appreciated that the first content (C1) may be present within a range between any of the minimum and maximum percentages noted above.

[00166] The blend of abrasive particles may include a particular content of the second type of shaped abrasive particle. For example, the second content (C2) may be not greater than about 98% of the total content of the blend. In other embodiments, the second content may be not greater than about 95%, such as not greater than about 90%, not greater than about 85%, not greater than about 80%, not greater than about 75%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 15%, not greater than about 10%, or even not greater than about 5%. Still, in one non-limiting embodiment, the second content (C2) may be present in an amount of at least about 1% of the total content of the blend. For example, the second content may be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, or even at least about 95%. It will be appreciated that the second content (C2) can be within a range between any of the minimum and maximum percentages noted above.

[00167] In accordance with another embodiment, the blend of abrasive particles may have a blend ratio (C1/C2) that may define a ratio between the first content (C1) and the second content (C2). For example, in one embodiment, the blend ratio (C1/C2) may be not greater than about 10. In yet another embodiment, the blend ratio (C1/C2) may be not greater than about 8, such as not greater than about 6, not greater than about 5, not greater than about 4, not greater than about 3, not greater than about 2, not greater than about 1.8, not greater than about 1.5, not greater than about 1.2, not greater than about 1, not greater than about 0.9, not greater than about 0.8, not greater than about 0.7, not greater than about 0.6, not greater than about 0.5, not greater than about 0.4, not greater than about 0.3, or even not greater than about 0.2. Still, in another non-limiting embodiment, the blend ratio (C1/C2) may be at least about 0.1, such as at least about 0.15, at least about 0.2, at least about 0.22, at least about 0.25, at least about 0.28, at least about 0.3, at least about 0.32, at least about 0.3, at least about 0.4, at least about 0.45, at least about 0.5, at least about 0.55, at least about 0.6, at least about 0.65, at least about 0.7, at least about 0.75, at least about 0.8, at least about 0.9, at least about 0.95, at least about 1, at least about 1.5, at least about 2, at least about 3, at least about

4, or even at least about 5. It will be appreciated that the blend ratio (C1/C2) may be within a range between any of the minimum and maximum values noted above.

[00168] In at least one embodiment, the blend of abrasive particles can include a majority content of shaped abrasive particles. That is, the blend can be formed primarily of shaped abrasive particles, including, but not limited to, a first type of shaped abrasive particle and a second type of shaped abrasive particle. In at least one particular embodiment, the blend of abrasive particles can consist essentially of the first type of shaped abrasive particle and the second type of shaped abrasive particle. However, in other non-limiting embodiments, the blend may include other types of abrasive particles. For example, the blend may include a third type of abrasive particle that may include a conventional abrasive particle or a shaped abrasive particle. The third type of abrasive particle may include a diluent type of abrasive particle having an irregular shape, which may be achieved through conventional crushing and comminution techniques.

[00169] According to another embodiment, the blend of abrasive particles can include a plurality of shaped abrasive particles and each of the shaped abrasive particles of the plurality may be arranged in a controlled orientation relative to a backing, such as a substrate of a coated abrasive article. Suitable exemplary controlled orientations can include at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation. In at least one embodiment, the plurality of shaped abrasive particles having a controlled orientation can include at least a portion of the first type of shaped abrasive particles of the blend, at least a portion of the second type of shaped abrasive particles of the blend, and a combination thereof. More particularly, the plurality of shaped abrasive particles having a controlled orientation can include all of the first type of shaped abrasive particles. In still another embodiment, the plurality of shaped abrasive particles arranged in a controlled orientation relative to the backing may include all of the second type of shaped abrasive particles within the blend of abrasive particles.

[00170] FIG. 7 includes a top view illustration of a portion of a coated abrasive article including shaped abrasive particles having controlled orientation. As illustrated, the coated abrasive article 700 includes a backing 701 that can be defined by a longitudinal axis 780 that extends along and defines a length of the backing 701 and a lateral axis 781 that extends along and defines a width of the backing 701. In accordance with an embodiment, a shaped abrasive particle 702 can be located in a first, predetermined position 712 defined by a particular first lateral position relative to the lateral axis of 781 of the backing 701 and a first

longitudinal position relative to the longitudinal axis 780 of the backing 701. Furthermore, a shaped abrasive particle 703 may have a second, predetermined position 713 defined by a second lateral position relative to the lateral axis 781 of the backing 701, and a first longitudinal position relative to the longitudinal axis 780 of the backing 701 that is substantially the same as the first longitudinal position of the shaped abrasive particle 702. Notably, the shaped abrasive particles 702 and 703 may be spaced apart from each other by a lateral space 721, defined as a smallest distance between the two adjacent shaped abrasive particles 702 and 703 as measured along a lateral plane 784 parallel to the lateral axis 781 of the backing 701. In accordance with an embodiment, the lateral space 721 can be greater than zero, such that some distance exists between the shaped abrasive particles 702 and 703. However, while not illustrated, it will be appreciated that the lateral space 721 can be zero, allowing for contact and even overlap between portions of adjacent shaped abrasive particle.

[00171] As further illustrated, the coated abrasive article 700 can include a shaped abrasive particle 704 located at a third, predetermined position 714 defined by a second longitudinal position relative to the longitudinal axis 780 of the backing 701 and also defined by a third lateral position relative to a lateral plane 785 parallel to the lateral axis 781 of the backing 701 and spaced apart from the lateral axis 784. Further, as illustrated, a longitudinal space 723 may exist between the shaped abrasive particles 702 and 704, which can be defined as a smallest distance between the two adjacent shaped abrasive particles 702 and 704 as measured in a direction parallel to the longitudinal axis 780. In accordance with an embodiment, the longitudinal space 723 can be greater than zero. Still, while not illustrated, it will be appreciated that the longitudinal space 723 can be zero, such that the adjacent shaped abrasive particles are touching, or even overlapping each other.

[00172] FIG. 8A includes a top view illustration of a portion of an abrasive article including shaped abrasive particles in accordance with an embodiment. As illustrated, the abrasive article 800 can include a shaped abrasive particle 802 overlying a backing 801 in a first position having a first rotational orientation relative to a lateral axis 781 defining the width of the backing 801. In particular, the shaped abrasive particle 802 can have a predetermined rotational orientation defined by a first rotational angle between a lateral plane 884 parallel to the lateral axis 781 and a dimension of the shaped abrasive particle 802. Notably, reference herein to a dimension of the shaped abrasive particle 802 can include reference to a bisecting axis 831 of the shaped abrasive particle 802, such bisecting axis 831 extending through a center point 821 of the shaped abrasive particle 802 along a surface (e.g., a side or an edge)

connected to (directly or indirectly) the backing 801. Accordingly, in the context of a shaped abrasive particle positioned in a side orientation, (see, e.g., FIG. 6), the bisecting axis 831 can extend through a center point 821 and in the direction of the width (w) of a side 833 closest to the surface of the backing 801.

[00173] In certain embodiments, the predetermined rotational orientation of the shaped abrasive particle 802 can be defined by a predetermined rotational angle 841 that defines the smallest angle between the bisecting axis 831 and the lateral plane 884, both of which extend through the center point 821 as viewed from the top down in FIG. 8A. In accordance with an embodiment, the predetermined rotational angle 841, and thus the predetermined rotational orientation, can be 0º. In other embodiments, the predetermined rotational angle defining the predetermined rotational orientation can be greater, such as at least about 2º, at least about 5º, at least about 10º, at least about 15º, at least about 20º, at least about 25º, at least about 30º, at least about 35º, at least about 40º, at least about 45º, at least about 50º, at least about 55º, at least about 60º, at least about 70º, at least about 80º, or even at least about 85º. Still, the predetermined rotational orientation as defined by the rotational angle 841 may be not greater than about 90º, such as not greater than about 85º, not greater than about 80º, not greater than about 75º, not greater than about 70º, not greater than about 65º, not greater than about 60º, such as not greater than about 55º, not greater than about 50º, not greater than about 45º, not greater than about 40º, not greater than about 35º, not greater than about 30º, not greater than about 25º, not greater than about 20º, such as not greater than about 15º, not greater than about 10º, or even not greater than about 5º. It will be appreciated that the predetermined rotational orientation can be within a range between any of the above minimum and maximum angles.

[00174] FIG. 8B includes a perspective view illustration of a portion of the abrasive article 800 including the shaped abrasive particle 802 having a triangular two-dimensional shape. As illustrated, the abrasive article 800 can include the shaped abrasive particle 802 overlying the backing 801 in a first position 812 such that the shaped abrasive particle 802 includes a first rotational orientation relative to the lateral axis 781 defining the width of the backing 801. Certain aspects of the predetermined orientation of a shaped abrasive particle may be described by reference to a x, y, z three-dimensional axis as illustrated. For example, the predetermined longitudinal orientation of the shaped abrasive particle 802 may be described by reference to the position of the shaped abrasive particle 802 relative to the y-axis, which extends parallel to the longitudinal axis 780 of the backing 801. Moreover, the

predetermined lateral orientation of the shaped abrasive particle 802 may be described by reference to the position of the shaped abrasive particle on the x-axis, which extends parallel to the lateral axis 781 of the backing 801. Furthermore, the predetermined rotational orientation of the shaped abrasive particle 802 may be defined with reference to a bisecting axis 831 that extends through the center point 821 of the side 833 of the shaped abrasive particle 802. Notably, the side 833 of the shaped abrasive particle 802 may be connected either directly or indirectly to the backing 801. In a particular embodiment, the bisecting axis 831 may form an angle with any suitable reference axis including, for example, the x-axis that extends parallel to the lateral axis 781. The predetermined rotational orientation of the shaped abrasive particle 802 may be described as a rotational angle formed between the x-axis and the bisecting axis 831, which rotational angle is depicted in FIG. 8B as angle 841. Notably, the controlled placement of a plurality of shaped abrasive particles on the backing of the abrasive article may facilitate improved performance of the abrasive article.

[00175] FIG. 9 includes a perspective view illustration of a portion of an abrasive article including shaped abrasive particles having predetermined orientation characteristics relative to a grinding direction in accordance with an embodiment. In one embodiment, the abrasive article 900 can include a shaped abrasive particle 902 having a predetermined orientation relative to another shaped abrasive particle 903 and/or relative to a grinding direction 985. The grinding direction 985 may be an intended direction of movement of the abrasive article relative to a workpiece in a material removal operation. In particular instances, the grinding direction 985 may be defined relative to the dimensions of the backing 901. For example, in one embodiment, the grinding direction 985 may be substantially perpendicular to the lateral axis 981 of the backing and substantially parallel to the longitudinal axis 980 of the backing 901. The predetermined orientation characteristics of the shaped abrasive particle 902 may define an initial contact surface of the shaped abrasive particle 902 with a workpiece. For example, the shaped abrasive particle 902 can include major surfaces 963 and 964 and side surfaces 965 and 966, each of which can extend between the major surfaces 963 and 964. The predetermined orientation characteristics of the shaped abrasive particle 902 can position the particle 902 such that the major surface 963 is configured to make initial contact with a workpiece before the other surfaces of the shaped abrasive particle 902 during a material removal operation. Such an orientation may be considered a major surface orientation relative to the grinding direction 985. More particularly, the shaped abrasive particle 902 can have a bisecting axis 931 having a particular orientation relative to the grinding direction 985.

For example, as illustrated, the vector of the grinding direction 985 and the bisecting axis 931 are substantially perpendicular to each other. It will be appreciated that, just as any range of predetermined rotational orientations relative to the backing are contemplated for a shaped abrasive particle, any range of orientations of the shaped abrasive particles relative to the grinding direction 985 are contemplated and can be utilized.

[00176] The shaped abrasive particle 903 can have one or more different predetermined orientation characteristics as compared to the shaped abrasive particle 902 and the grinding direction 985. As illustrated, the shaped abrasive particle 903 can include major surfaces 991 and 992, each of which can be joined by side surfaces 971 and 972. Moreover, as illustrated, the shaped abrasive particle 903 can have a bisecting axis 973 forming a particular angle relative to the vector of the grinding direction 985. As illustrated, the bisecting axis 973 of the shaped abrasive particle 903 can have a substantially parallel orientation with the grinding direction 985 such that the angle between the bisecting axis 973 and the grinding direction 985 is essentially 0 degrees. Accordingly, the predetermined orientation characteristics of the shaped abrasive particle 903 facilitate initial contact of the side surface 972 with a workpiece before any of the other surfaces of the shaped abrasive particle 903. Such an orientation of the shaped abrasive particle 903 may be considered a side surface orientation relative to the grinding direction 985.

[00177] Still, in one non-limiting embodiment, it will be appreciated that an abrasive article can include one or more groups of shaped abrasive particles that can be arranged in one or more predetermined distributions relative to the backing, a grinding direction, and/or each other. For example, one or more groups of shaped abrasive particles, as described herein, can have a predetermined orientation relative to a grinding direction. Moreover, the abrasive articles herein can have one or more groups of shaped abrasive particles, each of the groups having a different predetermined orientation relative to a grinding direction. Utilization of groups of shaped abrasive particles having different predetermined orientations relative to a grinding direction may facilitate improved performance of the abrasive article.

[00178] FIG. 10 includes a top view illustration of a portion of an abrasive article in accordance with an embodiment. In particular, the abrasive article 1000 can include a first group 1001 including a plurality of shaped abrasive particles. As illustrated, the shaped abrasive particles can be arranged relative to each other one the backing 101 to define a predetermined distribution. More particularly, the predetermined distribution can be in the form of a pattern 1023 as viewed top-down, and more particularly defining a triangular

shaped two-dimensional array. As further illustrated, the first group 1001 can be arranged on the abrasive article 1000 defining a predetermined macro-shape 1031 overlying the backing 101. In accordance with an embodiment, the macro-shape 1031 can have a particular two-dimensional shape as viewed top-down. Some exemplary two-dimensional shapes can include polygons, ellipsoids, numerals, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, Arabic alphabet characters, Kanji characters, complex shapes, irregular shapes, designs, any a combination thereof. In particular instances, the formation of a group having a particular macro-shape may facilitate improved performance of the abrasive article.

[00179] As further illustrated, the abrasive article 1000 can include a group 1004 including a plurality of shaped abrasive particles which can be arranged on the surface of the backing 101 relative to each other to define a predetermined distribution. Notably, the predetermined distribution can include an arrangement of the plurality of the shaped abrasive particles that define a pattern 422, and more particularly, a generally quadrilateral pattern. As illustrated, the group 1004 can define a macro-shape 1034 on the surface of the abrasive article 1000. In one embodiment, the macro-shape 1034 of the group 1004 can have a two-dimensional shape as viewed top down, including for example a polygonal shape, and more particularly, a generally quadrilateral (diamond) shape as viewed top down on the surface of the abrasive article 1000. In the illustrated embodiment of FIG. 10, the group 1001 can have a macro-shape 1031 that is substantially the same as the macro-shape 1034 of the group 1004. However, it will be appreciated that in other embodiments, various different groups can be used on the surface of the abrasive article, and more particularly wherein each of the different groups has a different macro-shape relative to each other.

[00180] As further illustrated, the abrasive article can include groups 1001, 1002, 1003, and 1004 which can be separated by channel regions 1021 and 1024 extending between the groups 1001-1004. In particular instances, the channel regions 1021 and 1024 can be substantially free of shaped abrasive particles. Moreover, the channel regions 1021 and 1024 may be configured to move liquid between the groups 1001-1004 and further improve swarf removal and grinding performance of the abrasive article. Furthermore, in a certain embodiment, the abrasive article 1000 can include channel regions 1021 and 1024 extending between groups 1001-1004, wherein the channel regions 1021 and 1024 can be patterned on the surface of the abrasive article 1000. In particular instances, the channel regions 1021 and

1024 can represent a regular and repeating array of features extending along a surface of the abrasive article.

[00181] The fixed abrasive articles of the embodiments herein can be utilized in various material removal operations. For example, fixed abrasive articles herein can be used in methods of removing material from a workpiece by moving the fixed abrasive article relative to the workpiece. The relative movement between the fixed abrasive and the workpiece can facilitate removal of the material from the surface of the workpiece. Various workpieces can be modified using the fixed abrasive articles of the embodiments herein, including but not limited to, workpieces comprising inorganic materials, organic materials, and a combination thereof. In a particular embodiment, the workpiece may include a metal, such as a metal alloy. In one particular instance, the workpiece can consist essentially of a metal or metal alloy, such as stainless steel.

EXAMPLES

[00182] Example 1

[00183] Four samples of shaped abrasive particles were tested for comparison of performance. A first sample, Sample S1, was initially formed from a mixture including approximately 45-50 wt% boehmite. The boehmite was obtained from Sasol Corp. as Catapal B and modified by autoclaving a 30 % by weight mixture of the Catapal B with deionized water and nitric acid. The nitric acid-to-boehmite ratio was approximately 0.025 in the autoclave and treated at 100 °C to 250 °C for a time ranging from 5 minutes to 24 hours. The autoclaved Catapal B sol was then dried by conventional means. One may also use an alternative boehmite, commercially available as Disperal from Sasol Corp. The boehmite was mixed and seeded with 1% alpha alumina seeds relative to the total alumina content of the mixture. The alpha alumina seeds were made by milling of corundum using conventional techniques, described for example in US 4,623,364. The mixture also included 45-50 wt% water and 2.5–7 wt% additional nitric acid depending on the desired viscosity of the mixture, which were used to form the gel mixture. The ingredients were mixed in a planetary mixer of conventional design and mixed under reduced pressure to remove gaseous elements from the mixture (e.g., bubbles).

[00184] After gelling, the mixture was deposited by hand into openings of a production tool made of stainless steel. The openings in the production tool were open to both sides of the production tool, such that they were apertures extending through the entire thickness of the production tool. The cavities or openings of the production tool had a shape approximately

the same as the shape of the particles provided herein. All samples were made with a production tool made of stainless steel with the exception of the particles of Sample S7, which was made with a production tool made of steel. The surfaces of the openings in the production tool were coated with a lubricant of olive oil to facilitate removal of the precursor shaped abrasive particles from the production tool. The gel was placed in the openings of the production tool and dried at room temperature for at least 12 hours. After drying, the precursor shaped abrasive particles were removed from the screen and sintered between 1250-1400 °C for approximately 10 minutes.

[00185] The shaped abrasive particles of Sample S1 had a two-dimensional shape of an equilateral triangle as provided in the image of FIG. 27, having an average width of about 1400 microns and height of approximately 300 microns. The body was formed essentially of a seeded sol-gel alumina material having an average grain size of less than 1 micron. The shaped abrasive particles of Sample S1 had an average strength of approximately 847 MPa, an average tip sharpness of approximately 20 microns, a Shape Index of approximately 0.5, and a 3SF of approximately 1.7.

[00186] A second sample, Sample S2, was formed using the same process used to form the shaped abrasive particles of Sample S1. Sample S2 included shaped abrasive particles having a two-dimensional, pentagon shape as provided in the image of FIG. 28. The body had an average width of approximately 925 microns and height of approximately 300 microns. The body was formed essentially of a seeded sol-gel alumina material having an average grain size of less than 1 micron. The shaped abrasive particles of Sample S2 had an average strength of approximately 847 MPa, an average tip sharpness of approximately 20 microns, a Shape Index of approximately 0.5, and a 3SF of approximately 1.7.

[00187] A third sample, Sample S3, was formed using the same process used to form the shaped abrasive particles of Sample S1. Sample S3 includes shaped abrasive particles having an oblique, truncated two-dimensional shape as provided in the image of FIG. 29. The body was formed essentially of a seeded sol-gel alumina material having an average grain size of less than 1 micron. The body had an average width of approximately 925 microns and a height of approximately 300 microns. The shaped abrasive particles of Sample S3 had an average strength of approximately 847 MPa, an average tip sharpness of approximately 20 microns, a Shape Index of approximately 0.63, and a 3SF of approximately 2.7.

[00188] A fourth sample, Sample CS4, was a conventional shaped abrasive particle commercially available as 3M984F from 3M Corporation. The body had an average width of

1400 microns and a height of approximately 300 microns. The shaped abrasive particles of Sample CS4 had a rare-earth element doped alpha-alumina composition, an average tip sharpness of approximately 20 microns, an average strength of approximately 606 MPa, a Shape Index of 0.5, and a 3SF of approximately 1.2. FIG. 30 includes an image of a shaped abrasive particle from Sample CS4.

[00189] All samples were tested according to a single grit grinding test (SGGT) in a major surface orientation and side orientation. In conducting the SGGT, one single shaped abrasive particle is held in a grit holder by a bonding material of epoxy. The shaped abrasive particle is secured in the desired orientation (i.e., major surface orientation or side surface orientation) and moved across a workpiece of 304 stainless steel for a scratch length of 8 inches using a wheel speed of 22 m/s and an initial scratch depth of 30 microns. The shaped abrasive particle produces a groove in the workpiece having a cross-sectional area (AR). For each sample set, each shaped abrasive particle completes 15 passes across the 8 inch length, 10 individual particles are tested for each of the orientation and the results are analyzed. The test measures the tangential force exerted by the grit on the workpiece, in the direction that is parallel to the surface of the workpiece and the direction of the groove, and the net change in the cross-sectional area of the groove from beginning to the end of the scratch length is measured to determine the shaped abrasive particle wear. The net change in the cross-sectional area of the groove for each pass can be measured. For the SGGT, the net cross-sectional area of the groove is defined as the difference between the cross-sectional area of the groove below the surface and the cross sectional area of the material displaced above the surface. Performance (Ft/A) is defined as the ratio of the tangential force to the net cross-sectional area of the groove.

[00190] The SGGT is conducted using two different orientations of the shaped abrasive particles relative to the workpiece. The SGGT is conducted with a first sample set of shaped abrasive particles in a major surface orientation (i.e., “front” in FIG. 18), wherein a major surface of each shaped abrasive particle is oriented perpendicular to the grinding direction such that the major surface initiates grinding on the workpiece. The results of the SGGT using the sample set of shaped abrasive particles in a major surface orientation allows for measurement of the grinding efficiency of the shaped abrasive particles in a major surface orientation.

[00191] The SGGT is also conducted with a second sample set of shaped abrasive particles in a side surface orientation (i.e., “side” in FIG. 18), wherein a side surface of each shaped

abrasive particle is oriented perpendicular to the grinding direction such that the side surface initiates grinding of the workpiece. The results of the SGGT test using the sample set of shaped abrasive particles in a side orientation allows for measurement of the grinding efficiency of the shaped abrasive particles in a side orientation.

[00192] FIG. 18 includes a plot of median force per total area removed from the workpiece, which is representative of data derived from the SGGT for all of the samples in the front (i.e., major surface orientation) and side (i.e., side surface orientation) orientations. The median force per total area removed is a measure of the grinding efficiency of the shaped abrasive particles, with lower force per total area removed as an indication of more efficient grinding performance. As illustrated, Sample S3 demonstrated the best performance of all samples tested. Without wishing to be tied to a particular theory it is noted that the combination of strength, tip sharpness, Shape Index and possibly the height of the shaped abrasive particles of Sample S3 were superior over all other samples, since Sample S3 demonstrated the most efficient grinding performance. In one theory, Samples S1 and S2, appear to have a strength that is too high in light of the tip sharpness and Shape Index, thus leading to grinding performance that is less suitable than compared to Sample S3. While Sample S4 appears to have a strength that is too low when combined with the particular tip sharpness and Shape Index, as the grains fractured too easily.

[00193] Example 2

[00194] Four samples of shaped abrasive particles were created and their performance in SGGT was compared. The first and second samples are samples S1 and S3 from Example 1 above.

[00195] A fifth sample, Sample S5, was formed using a machine including a die to extrude the gel mixture into openings of a production tool being translated under the die. These grains were used to form coated abrasive samples. Sample S5 included shaped abrasive particles having an equilateral triangle two-dimensional shape and having an average width of approximately 1400 microns and a height of approximately 300 microns. The shaped abrasive particles of Sample S5 were made of a seeded sol gel alumina material having an average strength of approximately 847 MPa, an average tip sharpness of approximately 80 microns, a Shape Index of approximately 0.5, and a 3SF of approximately 6.8. FIG. 19 includes an image of representative shaped abrasive particles from Sample S5.

[00196] A sixth sample, Sample S6, was formed using the same process used to form the shaped abrasive particles of Sample S5. Sample S6 included shaped abrasive particles having

an equilateral triangle two-dimensional shape and having an average width of approximately 1400 microns and a height of approximately 300 microns. The shaped abrasive particles of Sample S6 were made of a seeded sol gel alumina material having an average strength of approximately 847 MPa, an average tip sharpness of approximately 250 microns, a Shape Index of approximately 0.5, and a 3SF of approximately 21.2. FIG. 20 includes an image of representative shaped abrasive particles from Sample S6.

[00197] Each of the samples was tested in the SGGT. FIG. 21 includes a plot of median force per total area removed from the workpiece, which is representative of data derived from the SGGT for all of the samples in the front (i.e., major surface orientation) and side (i.e., side surface orientation) orientations. Sample S1 had a median force per area of 7.7 kN/mm^2, Sample S3 had a median force per area of 3.6 kN/mm^2, Sample S5 had a median force per area of 15.7 kN/mm^2, and Sample S6 had a median force per area of 22 kN/mm^2. As demonstrated by the data, Sample S3 demonstrated a remarkably lower median force per area and most efficient grinding characteristics, particularly compared to Sample S5 and S6.

[00198] Example 3

[00199] A seventh sample, Sample S7 was initially formed from a gel including boehmite, water, up to 4 wt% nitric acid, and up to 1% alpha alumina seeds. The solids loading of boehmite was between 45-50 wt% for the total weight of the gel. The gel was deposited into openings of a screen having the desired shape of the shaped abrasive particle. The screen was made of stainless steel. Prior to depositing the gel in the openings of the screen, the sides of the openings were sprayed with an oil as a releasing agent. After shaping, the dried shaped abrasive particles are calcined at approximately 1000 °C. A magnesia-containing compound of $Mg(NO_3)_2$ was dissolved in water to create a magnesia additive agent. Approximately 240 g of the aluminous material was impregnated with a sufficient amount of the magnesia additive agent to create shaped abrasive particles with 2.5 wt% MgO and 97.5 wt% alpha alumina after sintering at approximately 1360 °C for 10 minutes.

[00200] Abrasive particles of Samples S7, and CS5 were formed into coated abrasive articles CAS1, and CAS2, respectively. The samples CAS1 and CAS2 had the same construction, which is provided below. A backing of finished cloth of 47 pounds per ream was obtained and coated with a make formulation including a phenol formaldehyde resin as provided in Table 4. Using an electrostatic deposition process, 41 pounds per ream of abrasive particles from Samples S7 or CS5 were applied to the backing with the make coat. The structure was

dried in an oven for two hours at 80°C. It will be appreciated that the make coat is created such that sum of the components provided in Table 4 equal 100%.

[00201] TABLE 4: Make Coat Formulation

Make Formulation Component	Percentage
Filler NYAD Wollastonite 400	45-50 wt%
Wet Witcona 1260	0.10-.2 wt%
Resin, SI	45-50 wt%
Solmod Silane A1100	0.1-3 wt%
Water	0.1-1 wt%

[00202] The coated abrasive structures were then coated with a size coat having the formulation presented in Table 5. The construction was heat treated in an oven set for a final soak temperature of 100-120ºC, in which the sample was held for approximately 20-30 minutes. It will be appreciated that the size coat is created such that sum of the components provided in Table 5 equal 100%.

TABLE 5: Size Coat Formulation

Size Formulation Component	Percentage
Dye	2-4 wt%
Solmod Tamol 165A	0.5-2 wt%
Filler Syn Cryolite K	40-45 wt%
Resin Single Comp 94-908	50-55 wt%
DF70 Defoamer	0.1-0.2 wt%
Water	2-4 wt%

[00203] The coated abrasive sample was then placed into an oven to undergo heat treatment in which the oven temperature was set for a final soak temperature of approximately 110-120°C, in which the sample was held for approximately 10-12 hours.

[00204] A supersize coat having the formulation provided below in Table 6 was then applied to the Samples CAS1 and CAS2 and processed in the same manner as the size coat. It will be appreciated that the supersize coat is created such that sum of the components provided in Table 6 equal 100%.

[00205] Table 6: Supersize Coat Formulation

Supersize Formulation Component	Percentage
Dye	1-3 wt%
Solmod Cabosil	0.05-3 wt%
Solmod DAXAD 11	1-4 wt%
Filler Type A	63-67 wt%
Resin PF Prefere 80-5080A	20-25 wt%
DF70 Defoamer	0.1-0.2 wt%
Water	6-10 wt%

[00206] Each of the three different coated abrasive samples, CAS1 and CAS2, was tested according to a standardized grinding test using the conditions summarized in Table 7. Notably, two samples of coated abrasives were tested in each case to derive the results.

[00207] Table 7

Test conditions:		Test mode: Dry, straight plunge
		Constant MRR' = 4 inch^3/min/inch
		Belt speed (Vs) = 7500 sfpm (38 m/s)
		Work material: 304 ss
		Hardness: 96-104 HRB
		Size: 0.5 x 0.5 x 12 inches
		Contact width:0.5 in
		Contact Wheel: Steel
Measurements:		Power, Grinding Forces, MRR' and SGE
		Cum MR compared at SGE = 2.4 Hp.min/inch^3

[00208] Results of the above testing is illustrated in FIG. 22 depicting a plot of specific grinding energy per cumulative material removed, which is representative of data derived for all of the samples under the same testing protocol. As demonstrated by the data, Sample CAS1 exhibited a measurable lower specific grinding energy as compared Sample CAS2 over its entire life.

[00209] Example 4

[00210] An eighth sample, Sample S8 was initially formed from a gel including boehmite, water, up to 4 wt% nitric acid, and up to 1% alpha alumina seeds. The solids loading of boehmite was between 45-50 wt% for the total weight of the gel. The gel was deposited into openings of a screen having the desired shape of the shaped abrasive particle. The screen was made of stainless steel. Prior to depositing the gel in the openings of the screen, the sides of the openings were sprayed with an oil as a releasing agent. After shaping, the dried shaped abrasive particles were calcined at approximately 1000 °C. A zirconium basic carbonate (ZBC) solution was prepared with 46.1 g of ZBC dissolved into 61 g of 28 wt% HNO_3 solution. Approximately 170 g of the aluminous material was impregnated with a primary additive composition made of 10.8 g of magnesium nitrate hexahydrate and 13.6 g of the ZBC solution dissolved in 48.2 g of deionized water. The impregnated material is dried at 80 °C for approximately 12 hours. The shaped, impregnated particles were then sintered at approximately 1360 °C.

[00211] Sample S8 and CS5 were each formed into a coated abrasive article, CAS3 and CAS4, respectively, in the manner as set forth in Example 3 above.

[00212] FIG. 23 includes a plot of specific grinding energy per cumulative material removed, which is representative of data derived from the test for both samples under the same testing protocol. As demonstrated by the data, Sample CAS4 exhibited a measurable lower specific grinding energy as compared Sample CAS3 over its entire life.

[00213] The present application represents a departure from the state of the art. Conventional shaped abrasive particles have previously focused on making triangular shaped grains having the sharpest possible corners and edges. However, through empirical studies of shaped abrasive particles having various shapes and microstructures, it has been discovered that certain grain features (e.g., tip sharpness, strength, and Shape Index) appear to be interrelated and may be controlled with respect to each other to provide improved performance of a shaped abrasive particle. Additionally, as noted herein, the height may be related as well. Notably, in the present application, it is noted that one may not necessarily need to create a shaped abrasive particle with the sharpest features, but instead may control one or more of a combination of grain features, including tip sharpness, strength, Shape Index, and height relative to each other to improve the grinding performance of a shaped abrasive particle beyond conventional shaped abrasive particles. In particular, it is noted that the Shape Index may define an overall shape of the body and how stress is distributed throughout the body

during grinding, which when combined with a suitable tip sharpness and strength, may provide improved results over conventional triangular shaped abrasive particles having sharp tips. Moreover, while not completely understood and without wishing to be tied to a particular theory, it is thought that one or a combination of these features of the embodiments described herein facilitate the remarkable and unexpected performance of these particles in fixed abrasives, such as coated abrasive and bonded abrasives. For example, certain empirical evidence suggests that modification of the microstructure with the addition of certain additives can be used effectively to change the strength of the body, which when controlled with respect to other grain features, can facilitate formation of a shaped abrasive particle having remarkably improved results over what would otherwise be expected.

[00214] Certain features, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range.

[00215] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

[00216] The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The specification and illustrations are not intended to serve as an exhaustive and comprehensive description of all of the elements and features of apparatus and systems that use the structures or methods described herein. Separate embodiments may also be provided in combination in a single embodiment, and conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range. Many other embodiments may be apparent to skilled artisans only after reading this specification. Other embodiments may be used and derived from the disclosure, such that a structural substitution, logical substitution, or another change may be made without departing from the scope of the disclosure. Accordingly, the disclosure is to be regarded as illustrative rather than restrictive.

[00217] The description in combination with the figures is provided to assist in understanding the teachings disclosed herein. The following discussion will focus on specific implementations and embodiments of the teachings. This focus is provided to assist in describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings. However, other teachings can certainly be used in this application.

[00218] As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or inherent to such method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[00219] Also, the use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise. For example, when a single item is described herein, more than one item may be used in place of a single item. Similarly, where more than one item is described herein, a single item may be substituted for that more than one item.

[00220] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and may be found in reference books and other sources within the structural arts and corresponding manufacturing arts.

[00221] The above-disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments, which fall within the true scope of the present invention. Thus, to the maximum extent allowed by law, the scope of the present invention is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

[00222] The Abstract of the Disclosure is provided to comply with Patent Law and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description of the Drawings, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description of the Drawings, with each claim standing on its own as defining separately claimed subject matter.

[00223] Item 1. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a Shape Index within a range between at least about 0.48 and not greater than about 0.52 and a content of a magnesium-containing species within a range between at least about 1 wt% and not greater than about 4 wt% based on the total weight of the body.

[00224] Item 2. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body, and a strength within a range between at least about 350 MPa and not greater than about 600 MPa.

[00225] Item 3. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body, and wherein the body comprises a polycrystalline material including crystalline grains, wherein the average grain size is not greater than about 1 micron.

[00226] Item 4. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, and wherein the body consists essentially of alumina and magnesium.

[00227] Item 5. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt % based on a total weight of the body, and wherein the body comprises a content of a zirconium-containing species within a range between at least about 1 wt% and not greater than about 5 wt% based on the total weight of the body.

[00228] 6. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, wherein the body comprises a first dopant material in a range of at least about 0.5 wt% and not greater than 5 wt% based on a total weight of the body, and wherein the body comprises a second dopant material in a range of at least about 1 wt% and no greater than about 5 wt% based on the total weight of the body, the first dopant material being different than the second dopant material.

[00229] Item 7. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a Shape Index within a range between at least about 0.48 and not greater than about 0.52, wherein the Shape Index is approximately 0.5.

[00230] Item 8. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a strength of at least about 360 MPa, at least about 370 MPa, at least about 380 MPa, at least about 390 MPa, at least about 400 MPa, at least about 410 MPa, at least about 420 MPa, at least about 430 MPa, at least about 440 MPa, at least about 450 MPa, at least about 460 MPa, at least about 470 MPa, at least about 480 MPa.

[00231] Item 9. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a strength of not greater than about 590 MPa, not greater than about 580 MPa, not greater than about 570 MPa, not greater than about 560 MPa, not greater than about 550 MPa, not greater than about 540 MPa, not greater than about 530 MPa, not greater than about 520 MPa.

[00232] Item 10. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a tip sharpness within a range between not greater than about 80 microns and at least about 1 micron.

[00233] Item 11. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a tip sharpness of not greater than about 78 microns, not greater than about 76 microns, not greater than about 74 microns, not greater than about 72 microns, not greater than about 70 microns, not greater than about 68 microns, not greater than about 66 microns, not greater than about 64 microns, not greater than about 62 microns, not greater than about 60 microns, not greater than about 58 microns, not greater than about 56 microns, not greater than about 54 microns, not greater than about 52 microns, not greater than about 50 microns, not greater than about 48 microns, not greater than about 46 microns, not greater than about 44 microns, not greater than about 42 microns, not greater than about 40 microns, not greater than about 38 microns, not greater than about 36 microns, not greater than about 34 microns, not greater than about 32 microns, not greater than about 30 microns, not greater than about 38 microns, not greater than about 36 microns, not greater than about 34 microns, not greater than about 32 microns, not greater than about 30 microns, not greater than about 28 microns, not greater than about 26 microns, not greater than about 24 microns, not greater than about 22 microns, not greater than about 20 microns, not greater than about 18 microns, not greater than about 16 microns, not greater than about 14 microns, not greater than about 12 microns, not greater than about 10 microns.

[00234] Item 12. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a tip sharpness of at least about 2 microns, at least about 4 microns, at least about 6 microns, at least about 8 microns, at least about 10 microns, at least about 12 microns, at least about 14 microns, at least about 16 microns, at least about 18 microns, at least about 20 microns, at least about 22 microns, at least about 24 microns, at least about 26 microns, at least about 28 microns, at least about 30 microns, at least about 32 microns, at least about 34 microns, at least about 36 microns, at least about 38 microns, at least about 40 microns, at least about 42 microns, at least about 44 microns, at least about 46 microns, at least about 48 microns, at least about 50 microns, at least about 52 microns, at least about 54 microns, at least about 56 microns, at least about 58 microns, at least about 60 microns, at least about 62 microns, at least about 64 microns, at least about 66 microns, at least about 68 microns, at least about 70 microns.

[00235] Item 13. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a sharpness-shape-strength factor (3SF) within a range between about 0.7 and about 1.7.

[00236] Item 14. The shaped abrasive particle of any one of the foregoing items, wherein the body has a 3SF of at least about 0.72, at least about 0.75, at least about 0.78, at least about 0.8, at least about 0.82, at least about 0.85, at least about 0.88, at least about 0.90, at least about 0.92, at least about 0.95, at least about 0.98.

[00237] Item 15. The shaped abrasive particle of any one of the foregoing items, wherein the body has a 3SF of not greater than about 1.68, not greater than about 1.65, not greater than about 1.62, not greater than about 1.6, not greater than about 1.58, not greater than about 1.55, not greater than about 1.52, not greater than about 1.5, not greater than about 1.48, not greater than about 1.45, not greater than about 1.42, not greater than about 1.4, not greater than about 1.38, not greater than about 1.35, not greater than about 1.32, not greater than about 1.3, not greater than about 1.28, not greater than about 1.25, not greater than about 1.22, not greater than about 1.2, not greater than about 1.18, not greater than about 1.15, not greater than about 1.12, not greater than about 1.1.

[00238] Item 16. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a content of the magnesium-containing species of at least about 0.6 wt%, at least about 0.7 wt%, at least about 0.8 wt%, at least about 0.9 wt%, at least about 1 wt%, at least about 1.1 wt%, at least about 1.2 wt%, at least about 1.3 wt%, at least about 1.4 wt%, at least about 1.5 wt%, at least about 1.6 wt%, at least about 1.7 wt%, at least about 1.8 wt%, at least about 1.9 wt%, at least about 2 wt%, at least about 2.1 wt%, at least about 2.2 wt%, at least about 2.3 wt%, at least about 2.4 wt%, at least about 2.5 wt%.

[00239] Item 17. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a content of the magnesium-containing species of at least about at least about 2.1 wt%, at least about 2.2 wt%, at least about 2.3 wt%, at least about 2.4 wt%, at least about 2.5 wt%.

[00240] Item 18. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a content of the magnesium-containing species of not greater than about 4.9 wt%, not greater than about 4.8 wt%, not greater than about 4.7wt%, not greater than about 4.6 wt%, not greater than about 4.5 wt%, not greater than about 4.4 wt%, not greater than about 4.3 wt%, not greater than about 4.2wt%, not greater than about 4.1 wt%, not greater than about 4 wt%, not greater than about 3.9 wt%, not greater than about 3.8 wt%, not greater

than about 3.7wt%, not greater than about 3.6 wt%, not greater than about 3.5 wt%, not greater than about 3.4 wt%, not greater than about 3.3 wt%, not greater than about 3.2wt%, not greater than about 3.1 wt%, not greater than about 3 wt%, not greater than about 2.9 wt%, not greater than about 2.8 wt%, not greater than about 2.7wt%, not greater than about 2.6 wt%, not greater than about 2.5 wt%.

[00241] Item 19. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a content of the magnesium-containing species of not greater than about 3.9 wt%, not greater than about 3.8 wt%, not greater than about 3.7wt%, not greater than about 3.6 wt%, not greater than about 3.5 wt%, not greater than about 3.4 wt%, not greater than about 3.3 wt%, not greater than about 3.2wt%, not greater than about 3.1 wt%, not greater than about 3 wt%, not greater than about 2.9 wt%, not greater than about 2.8 wt%, not greater than about 2.7wt%, not greater than about 2.6 wt%, not greater than about 2.5 wt%.

[00242] Item 20. The shaped abrasive particle of any one of the foregoing items, wherein the body consists essentially of alumina and the magnesium-containing species.

[00243] Item 21. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises at least about 95 wt% alumina for the total weight of the body, at least about 95.1 wt%, at least about 95.2 wt%, at least about 95.3 wt%, at least about 95.4 wt%, at least about 95.5 wt%, at least about 95.6 wt%, at least about 95.7 wt%, at least about 95.8 wt%, at least about 95.9 wt%, at least about 96 wt%, at least about 96.1 wt%, at least about 96.2 wt%, at least about 96.3 wt%, at least about 96.4 wt%, at least about 96.5 wt%, at least about 96.6 wt%, at least about 96.7 wt%, at least about 96.8 wt%, at least about 96.9 wt%, at least about 97 wt%, at least about 97.1 wt%, at least about 97.2 wt%, at least about 975.3 wt%, at least about 97.4 wt%, at least about 97.5 wt%.

[00244] Item 22. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises not greater than about 99.5 wt% alumina for the total weight of the body, not greater than about 99.4 wt%, not greater than about 99.3wt%, not greater than about 99.2 wt%, not greater than about 99.1 wt%, not greater than about 99 wt%, not greater than about 98.9 wt%, not greater than about 98.8 wt%, not greater than about 98.7wt%, not greater than about 98.6 wt%, not greater than about 98.5 wt%, not greater than about 98.4 wt%, not greater than about 98.3 wt%, not greater than about 98.2 wt%, not greater than about 98.1wt%, not greater than about 98 wt%, not greater than about 97.9 wt%, not greater than about 97.8 wt%, not greater than about 97.7 wt%, not greater than about 97.6 wt%, not greater than about 97.5wt%.

[00245] Item 23. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a polycrystalline material including crystalline grains, wherein the average grain size is not greater than about 1 micron, not greater than about 0.9 microns, not greater than about 0.8 microns, not greater than about 0.7 microns, not greater than about 0.6 microns.

[00246] Item 24. The shaped abrasive particle of any one of the foregoing items, wherein the average grain size is at least about 0.01 microns, at least about 0.05 microns, at least about 0.06 microns, at least about 0.07 microns, at least about 0.08 microns, at least about 0.09 microns, at least about 0.1 microns, at least about 0.12 microns, at least about 0.15 microns, at least about 0.17 microns, at least about 0.2 microns.

[00247] Item 25. The shaped abrasive particle of any one of the foregoing items, wherein the body is essentially free of a binder, wherein the body is essentially free of an organic material, wherein the body is essentially free of rare earth elements, wherein the body is essentially free of iron.

[00248] Item 26. The shaped abrasive particle of any one of the foregoing items, wherein the body is formed from a seeded sol gel.

[00249] Item 27. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a substantially triangular two-dimensional shape.

[00250] Item 28. The shaped abrasive particle of any one of the foregoing items, wherein the body is coupled to a substrate as part of a fixed abrasive, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

[00251] Item 29. The shaped abrasive particle of any one of the foregoing items, wherein the substrate is a backing, wherein the backing comprises a woven material, wherein the backing comprises a non-woven material, wherein the backing comprises an organic material, wherein the backing comprises a polymer, wherein the backing comprises a material selected from the group consisting of cloth, paper, film, fabric, fleeced fabric, vulcanized fiber, woven material, non-woven material, webbing, polymer, resin, phenolic resin, phenolic-latex resin, epoxy resin, polyester resin, urea formaldehyde resin, polyester, polyurethane, polypropylene, polyimides, and a combination thereof.

[00252] Item 30. The shaped abrasive particle of any one of the foregoing items, wherein the backing comprises an additive selected from the group consisting of catalysts, coupling

agents, curants, anti-static agents, suspending agents, anti-loading agents, lubricants, wetting agents, dyes, fillers, viscosity modifiers, dispersants, defoamers, and grinding agents.

[00253] Item 31. The shaped abrasive particle of any one of the foregoing items, further comprising an adhesive layer overlying the backing, wherein the adhesive layer comprises a make coat, wherein the make coat overlies the backing, wherein the make coat is bonded directly to a portion of the backing, wherein the make coat comprises an organic material, wherein the make coat comprises a polymeric material, wherein the make coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

[00254] Item 32. The shaped abrasive particle of any one of the foregoing items, wherein the adhesive layer comprises a size coat, wherein the size coat overlies a portion of the plurality of shaped abrasive particles, wherein the size coat overlies a make coat, wherein the size coat is bonded directly to a portion of the plurality of shaped abrasive particles, wherein the size coat comprises an organic material, wherein the size coat comprises a polymeric material, wherein the size coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

[00255] Item 33. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height.

[00256] Item 34. The shaped abrasive particle of any one of the foregoing items, wherein the height (h) is at least about 100 microns, at least about 150 microns, at least about 175 microns, at least about 200 microns, at least about 225 microns, at least about 250 microns, at least about 275 microns, or even at least about 300 microns. 450 microns, such as at least about 475 microns, at least about 500 microns, and not greater than about 3 mm, not greater than about 2 mm, not greater than about 1.5 mm, not greater than about 1 mm, or even not greater than about 800 microns, not greater than about 600 microns, not greater than about 500 microns, not greater than about 475 microns, not greater than about 450 microns, not greater than about 425 microns, not greater than about 400 microns, not greater than about 375 microns, not greater than about 350 microns, not greater than about 325 microns, not

greater than about 300 microns, not greater than about 275 microns, not greater than about 250 microns.

[00257] Item 35. The shaped abrasive particle of any one of the foregoing items, wherein the width is at least about 600 microns, at least about 700 microns, at least about 800 microns, at least about 900 microns, and not greater than about 4 mm, not greater than about 3 mm, not greater than about 2.5 mm, not greater than about 2 mm.

[00258] Item 36. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a primary aspect ratio of width:length of at least about 1:1 and not greater than about 10:1.

[00259] Item 37. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a secondary aspect ratio defined by a ratio of width:height within a range between about 5:1 and about 1:1.

[00260] Item 38. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a tertiary aspect ratio defined by a ratio of length:height within a range between about 6:1 and about 1:1.

[00261] Item 39. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a percent flashing of not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 18%, not greater than about 15%, not greater than about 12%, not greater than about 10%, not greater than about 8%, not greater than about 6%, not greater than about 4%.

[00262] Item 40. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises a dishing value (d) of not greater than about 2, not greater than about 1.9, not greater than about 1.8, not greater than about 1.7, not greater than about 1.6, not greater than about 1.5, not greater than about 1.2, and at least about 0.9, at least about 1.0.

[00263] Item 41. The shaped abrasive particle of any one of the foregoing items, wherein the body further comprises a zirconium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body.

[00264] Item 42. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises at least about 0.6 wt% of a zirconium-containing species, or at least about 1 wt% of a zirconium-containing species, or at least about 1.5 wt% of a zirconium-containing species, or at least about 2.0 wt% of a zirconium-containing species, or at least about 2.5 wt% of a zirconium-containing species, or at least 3.0 wt% of a zirconium-containing species, or at

least 3.5 wt% of a zirconium-containing species, or at least 4.0 wt% of a zirconium-containing species, or at least 4.5 wt% of a zirconium-containing species.

[00265] Item 43. The shaped abrasive particle of any one of the foregoing items, wherein the body comprises no greater than about 5 wt% of a zirconium-containing species, or no greater than about 4.9 wt% of a zirconium-containing species, or no greater than 4.8 wt% of a zirconium-containing species, or no greater than 4.7 wt% of a zirconium-containing species, or no greater than 4.6 wt% of a zirconium-containing species, or no greater than 4.5 wt% of a zirconium-containing species, or no greater than 4.0 wt% of a zirconium-containing species, or no greater than 3.5 wt% of a zirconium-containing species, or no greater than 3.0 wt% of a zirconium-containing species, or no greater than 2.5 wt% of a zirconium-containing species, or no greater than 2.0 wt% of a zirconium-containing species, or no greater 1.5 wt% of a zirconium-containing species, or no greater than 1.0 wt% of a zirconium-containing species.

[00266] Item 44. The shaped abrasive particle of any one of the foregoing items, wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is in a range between about 1:4 and about 1:1.

[00267] Item 45. The shaped abrasive particle of any one of the foregoing items, wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is at least about 1:4, or at least about 1:3.5, or at least about 1:3, or at least about 1:2.5, or at least 1:2, or at least about 1:1.5, or at least about 1:1.

[00268] Item 46. The shaped abrasive particle of any one of the foregoing items, wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is no greater than about 1:1.

[00269] Item 47. The shaped abrasive particle of any one of the foregoing items, wherein the body further comprises a zirconium-containing species.

WHAT IS CLAIMED IS:

1. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a Shape Index within a range between at least about 0.48 and not greater than about 0.52 and a content of a magnesium-containing species within a range between at least about 1 wt% and not greater than about 4 wt% based on the total weight of the body.

2. The shaped abrasive particle of claim 1, wherein the body comprises a tip sharpness within a range between not greater than about 80 microns and at least about 1 micron.

3. The shaped abrasive particle of claim 1, wherein the body comprises a sharpness-shape-strength factor (3SF) within a range between about 0.7 and about 1.7.

4. The shaped abrasive particle of claim 1, wherein the body further comprises a zirconium-containing species.

5. The shaped abrasive particle of claim 1, wherein the body further comprises a zirconium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body.

6. The shaped abrasive particle of claim 5, wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is in a range of about 1:4 and about 1:1.

7. The shaped abrasive particle of claim 1, wherein the body is coupled to a substrate as part of a fixed abrasive, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

8. The shaped abrasive particle of claim 1, wherein the body comprises a polycrystalline material including crystalline grains, wherein the average grain size is not greater than about 0.7 microns.

9. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a substantially triangular two-dimensional shape, a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body, and wherein the body comprises a polycrystalline material including crystalline grains, wherein the average grain size is not greater than about 1 micron.

10. The shaped abrasive particle of claim 9, wherein the body comprises a Shape Index within a range between at least about 0.48 and not greater than about 0.52.

11. The shaped abrasive particle of claim 9, wherein the body further comprises a zirconium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt% based on the total weight of the body, and wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is in a range of about 1:4 and about 1:1.

12. The shaped abrasive particle of claim 9, wherein the body is coupled to a substrate as part of a fixed abrasive, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

13. The shaped abrasive particle of claim 9, wherein the body comprises a tip sharpness within a range between not greater than about 80 microns and at least about 1 micron.

14. The shaped abrasive particle of claim 9, wherein the body comprises a strength within a range between at least about 350 MPa and not greater than about 600 MPa.

15. A shaped abrasive particle comprising:

a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, wherein the body comprises a content of a magnesium-containing species within a range between at least about 0.5 wt% and not greater than about 5 wt % based on a total weight of the body, and wherein the body comprises a content of a zirconium-containing species within a range between at least about 1 wt% and not greater than about 5 wt% based on the total weight of the body.

16. The shaped abrasive particle of claim 15, wherein the body comprises a Shape Index of approximately 0.5.

17. The shaped abrasive particle of claim 15, wherein a wt% ratio of the zirconium-containing species to the magnesium-containing species is in a range of about 1:4 and about 1:1.

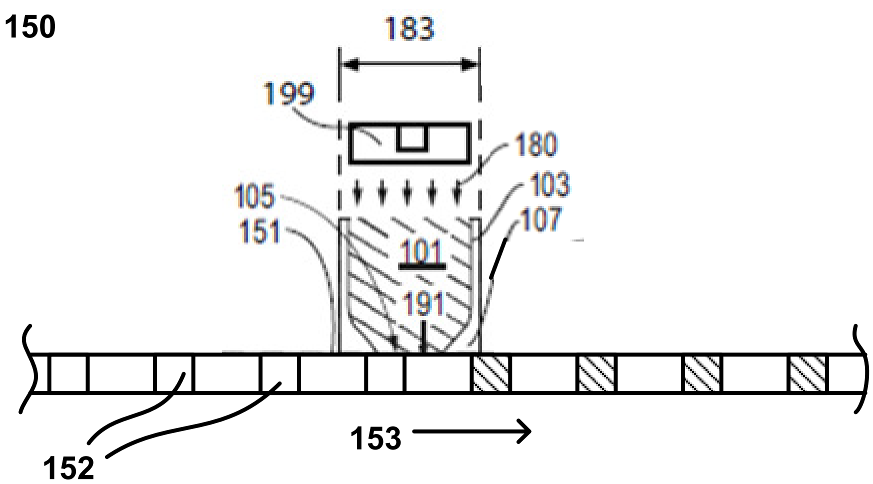
18. The shaped abrasive particle of claim 15, wherein the body is coupled to a substrate as part of a fixed abrasive, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

19. The shaped abrasive particle of claim 15, wherein the body comprises a sharpness-shape-strength factor (3SF) within a range between about 0.7 and about 1.7.

20. The shaped abrasive particle of claim 15, wherein the body comprises a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height.

ABSTRACT OF THE DISCLOSURE

A shaped abrasive particle including a body comprising a first major surface, a second major surface, and a side surface extending between the first major surface and the second major surface, the body having a Shape Index within a range between at least about 0.48 and not greater than about 0.52 and a content of a magnesium-containing species within a range between at least about 1 wt% and not greater than about 4 wt% based on the total weight of the body.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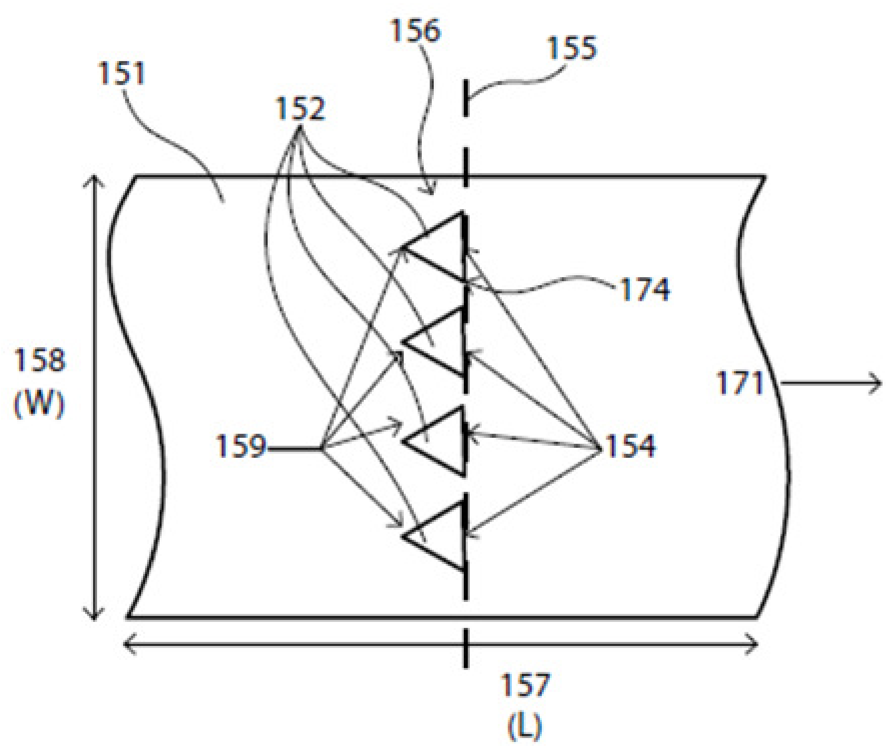
153

FIG. 1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174
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(W)
171
159
154
157
(L)

FIG. 2

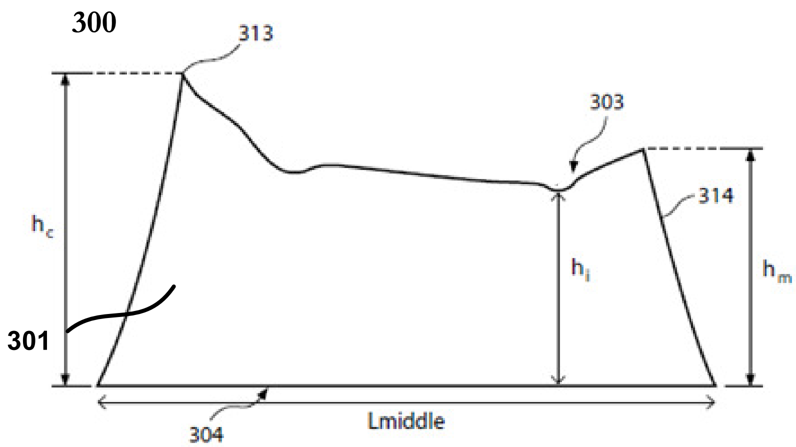


FIG. 3

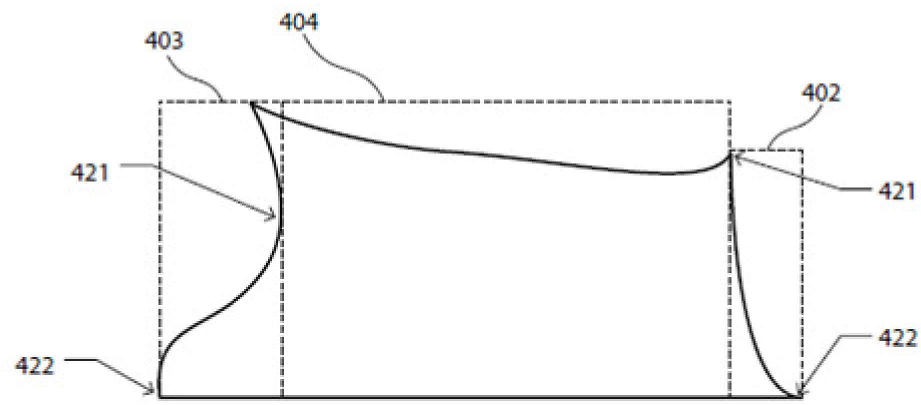


FIG. 4

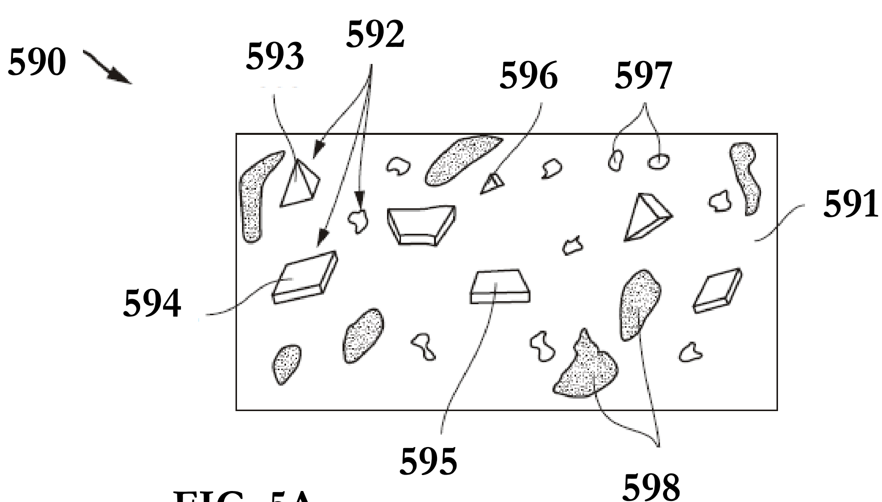


FIG. 5A

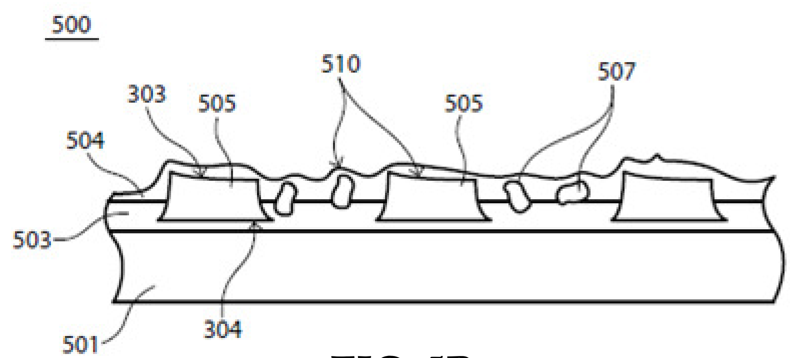
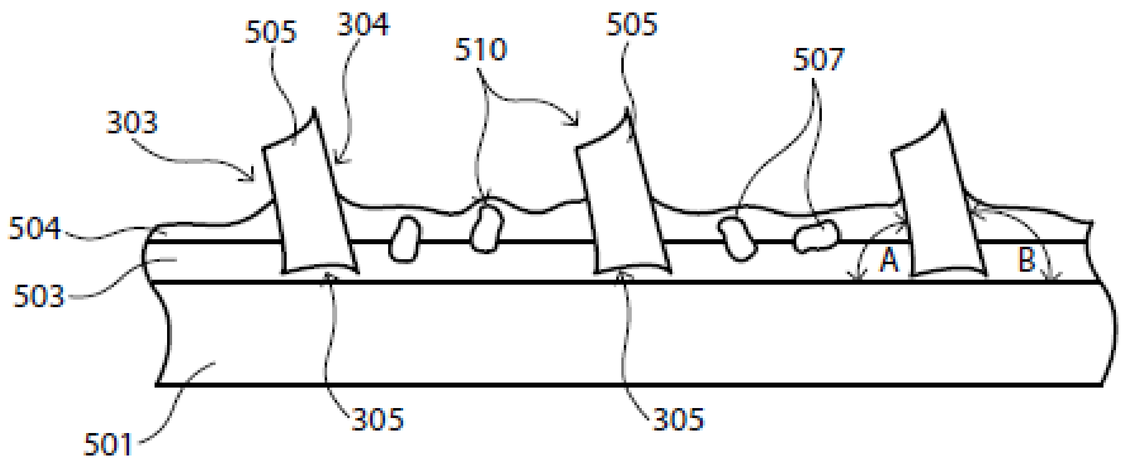


FIG. 5B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A
B
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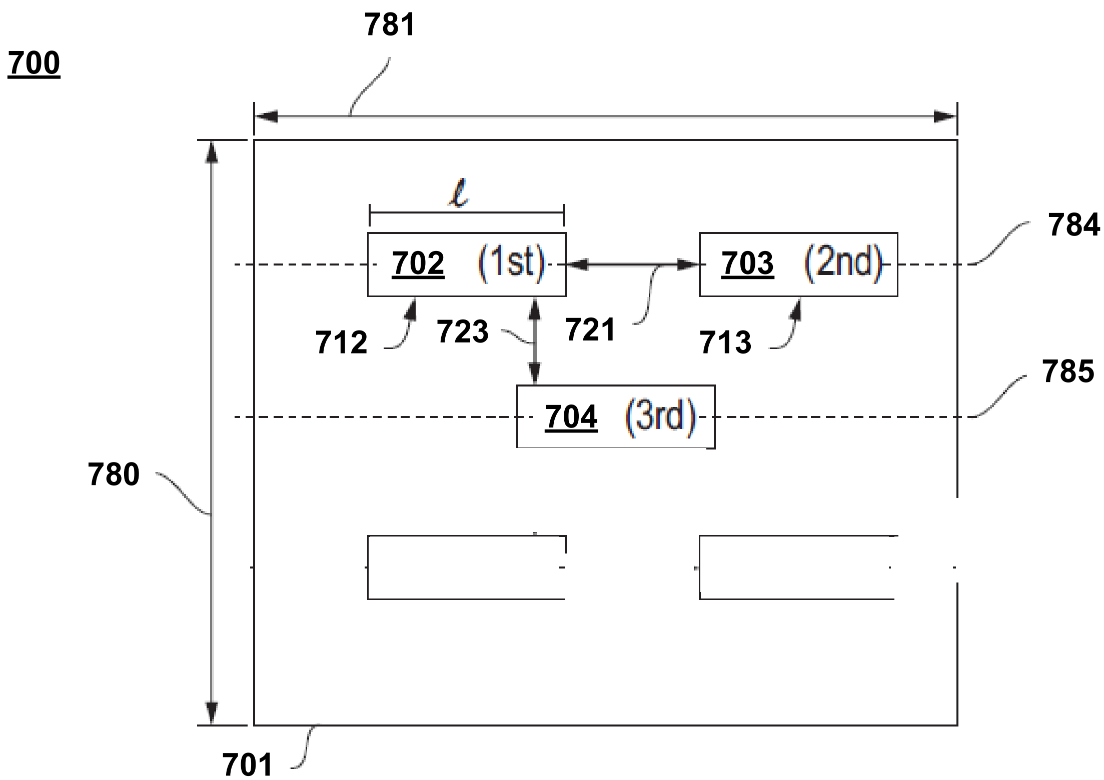
305

FIG. 6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ℓ
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703 (2nd)
784
712
723
721
713
785
704 (3rd)
780
701

FIG. 7

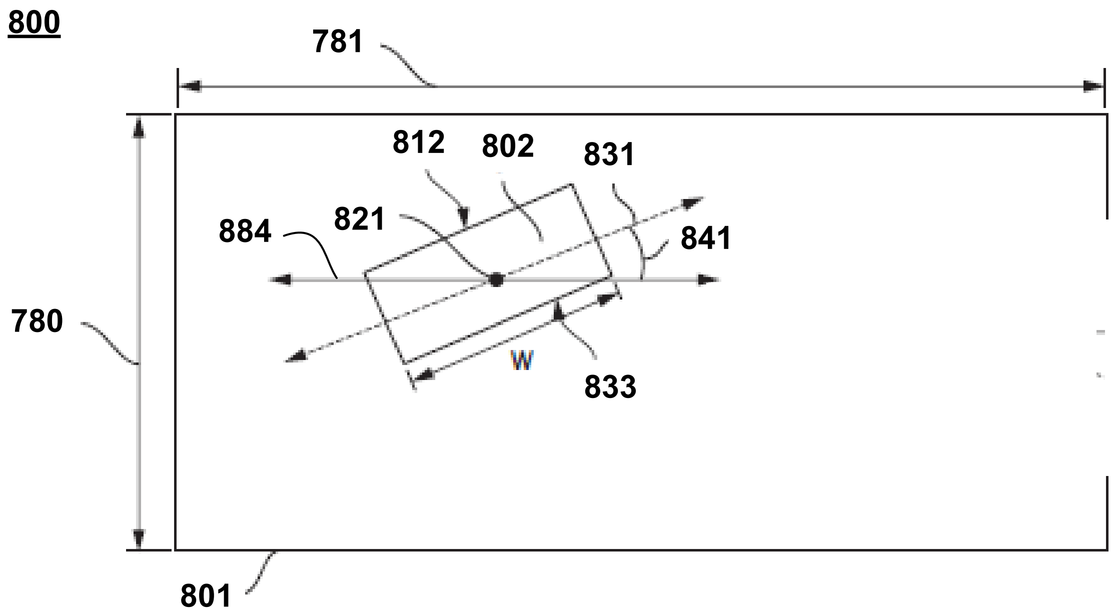
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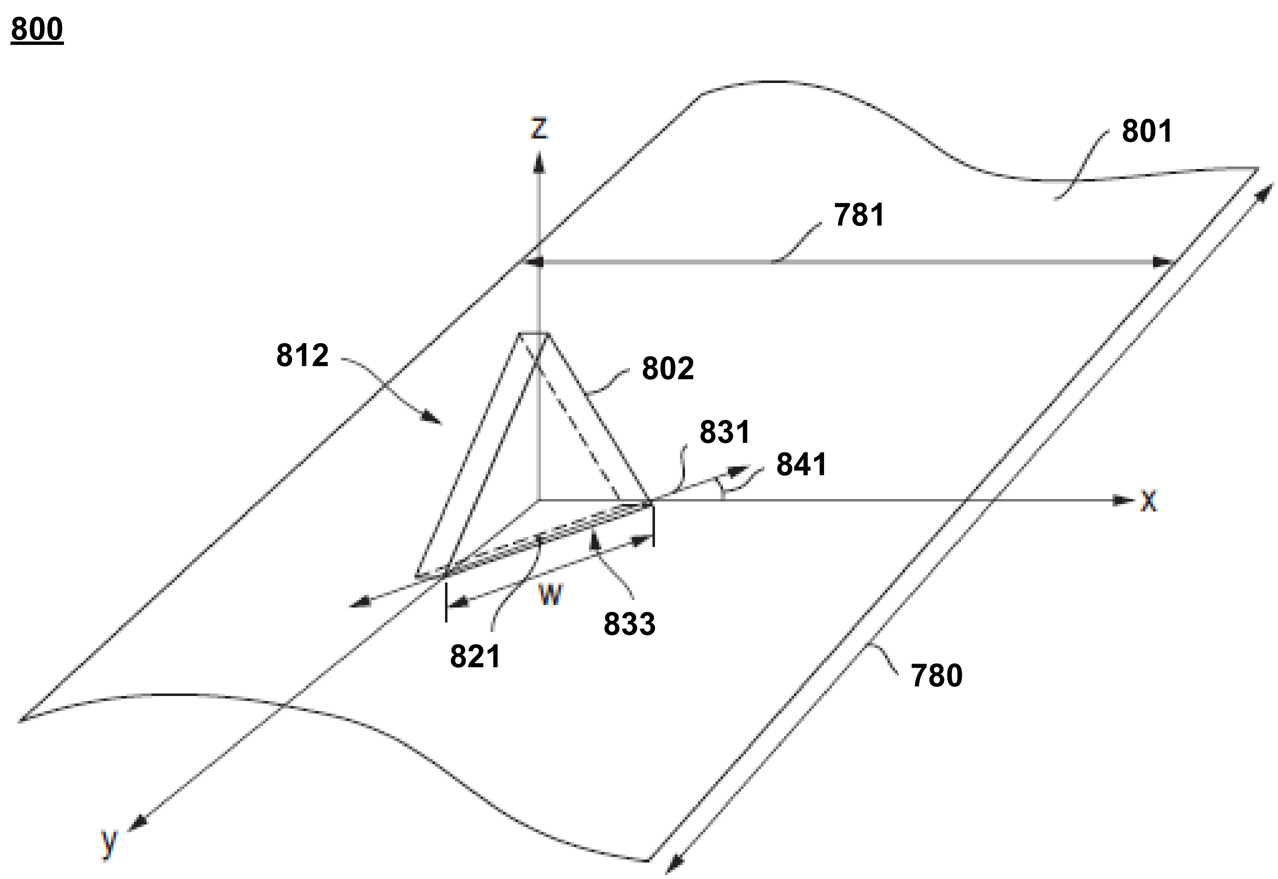
FIG. 8A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780
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FIG. 8B

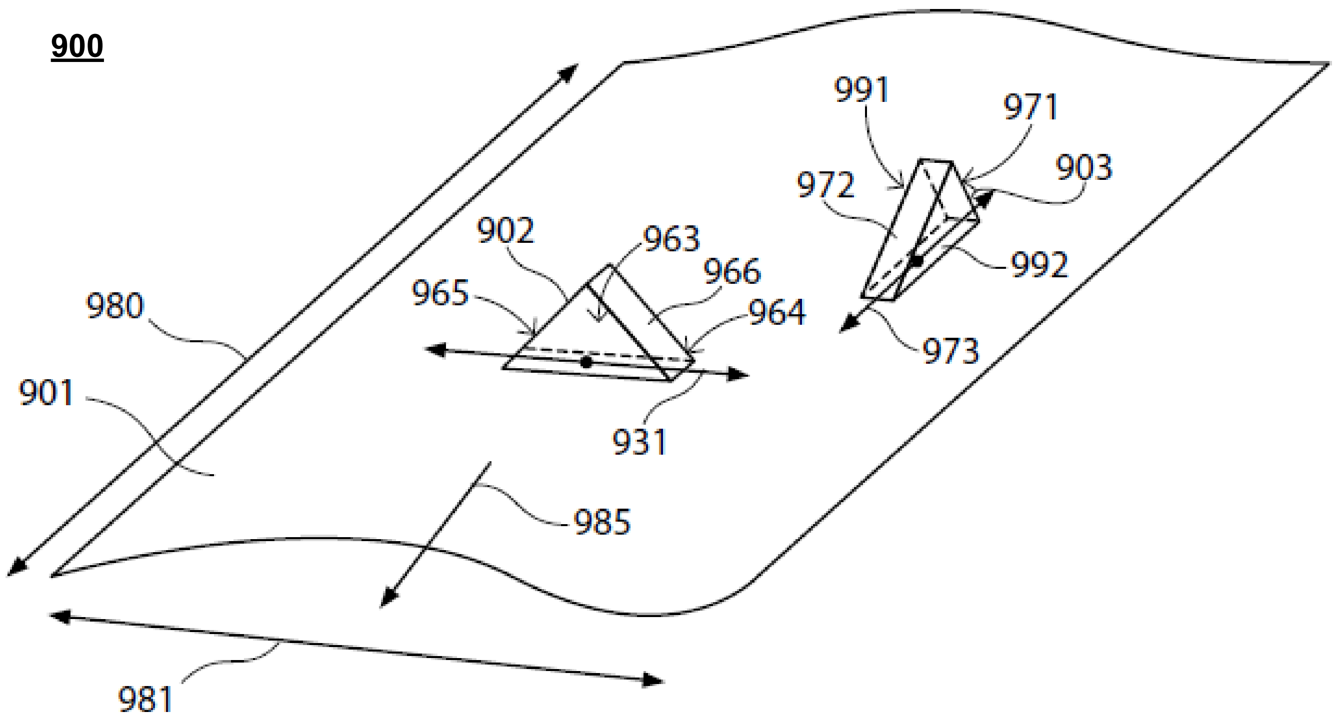
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FIG. 9

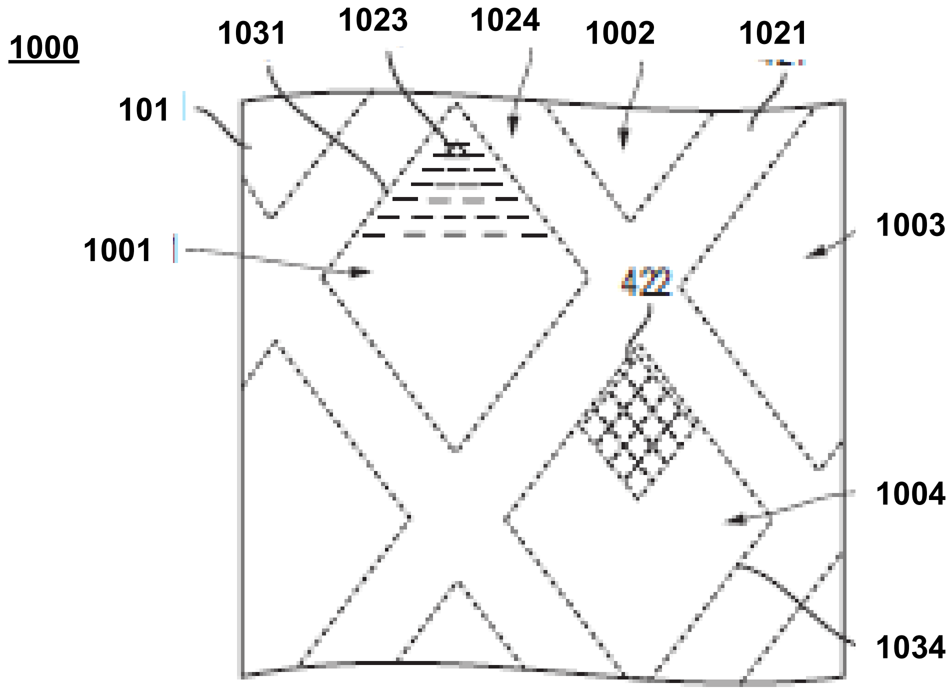
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FIG. 10

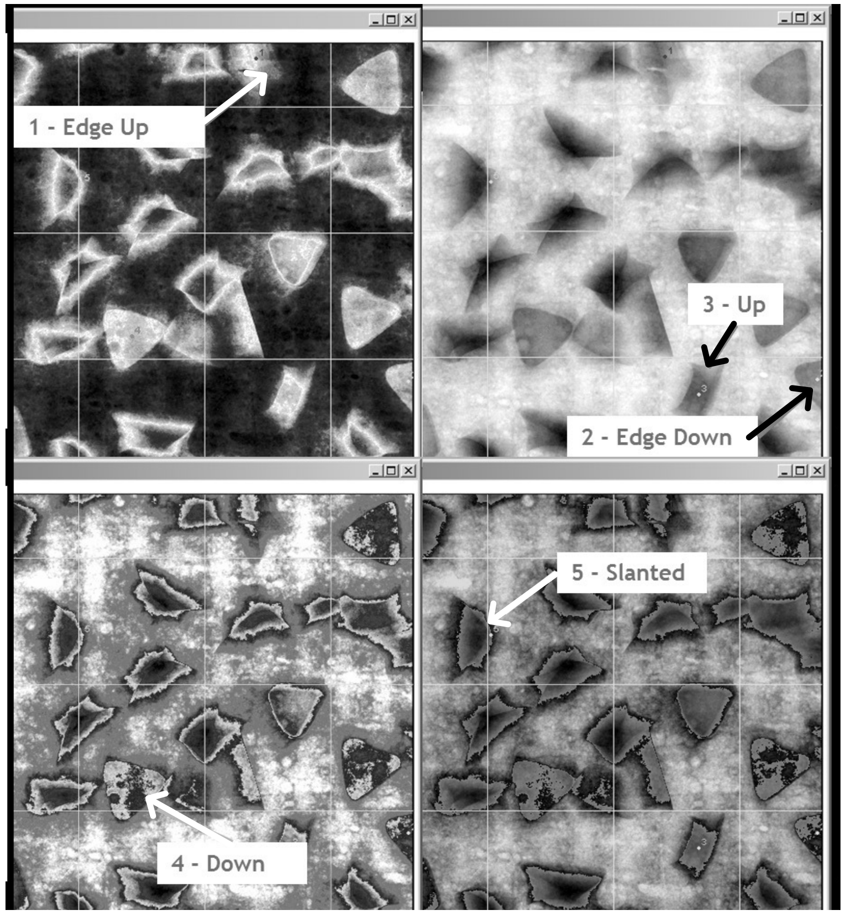

FIG. 11

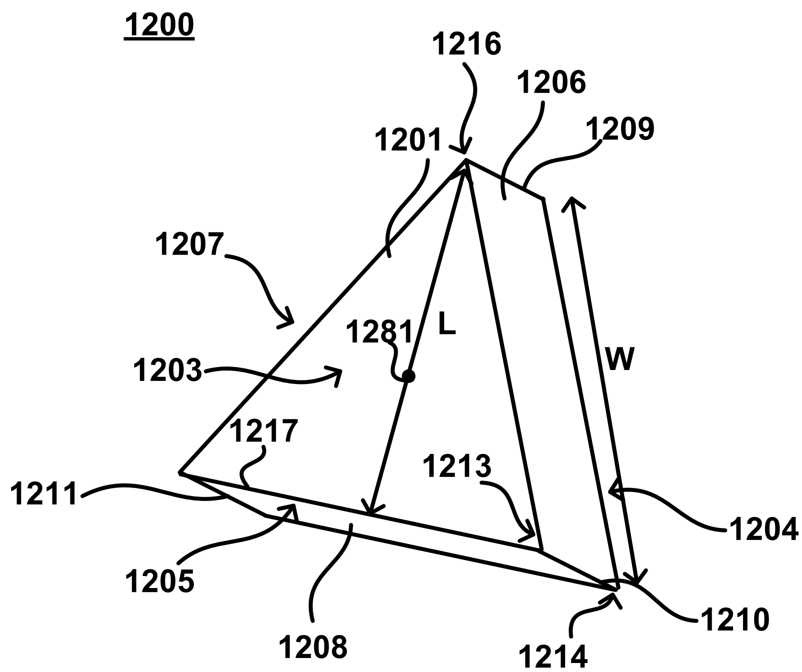

FIG. 12A

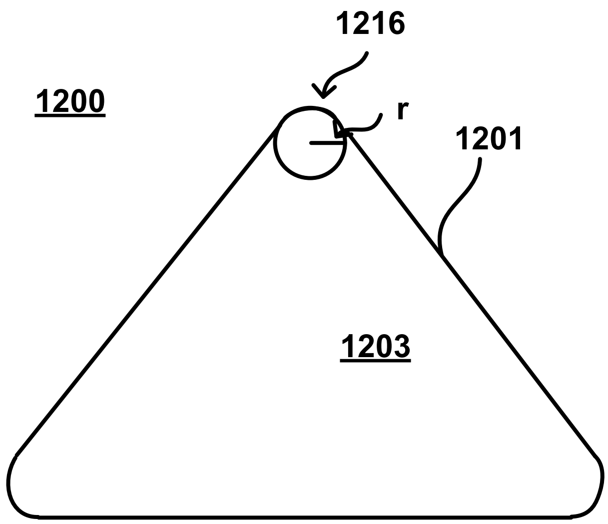

FIG. 12B

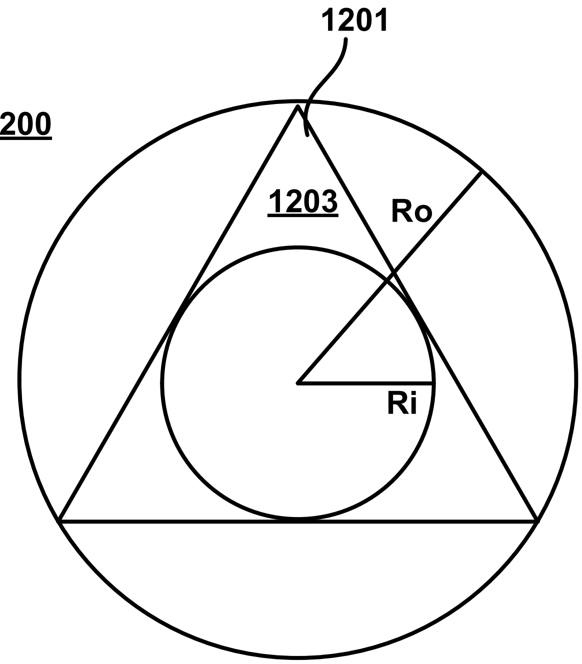

FIG. 12C

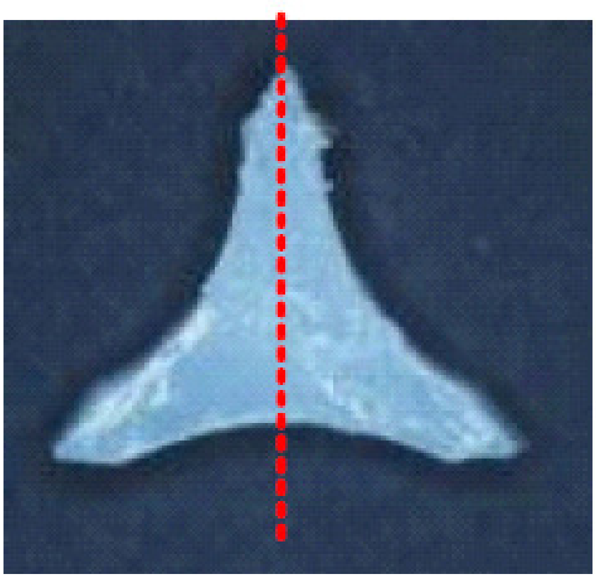

FIG. 12D

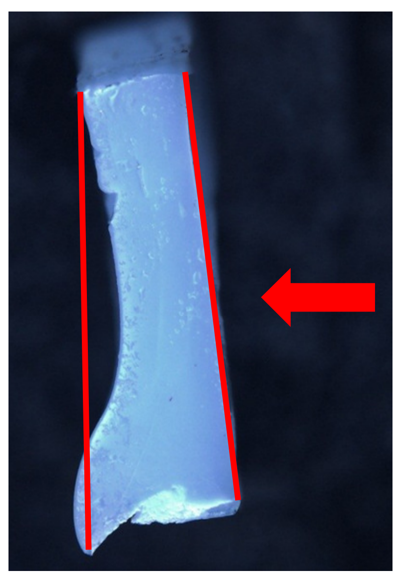

FIG. 12E

FIG. 12F

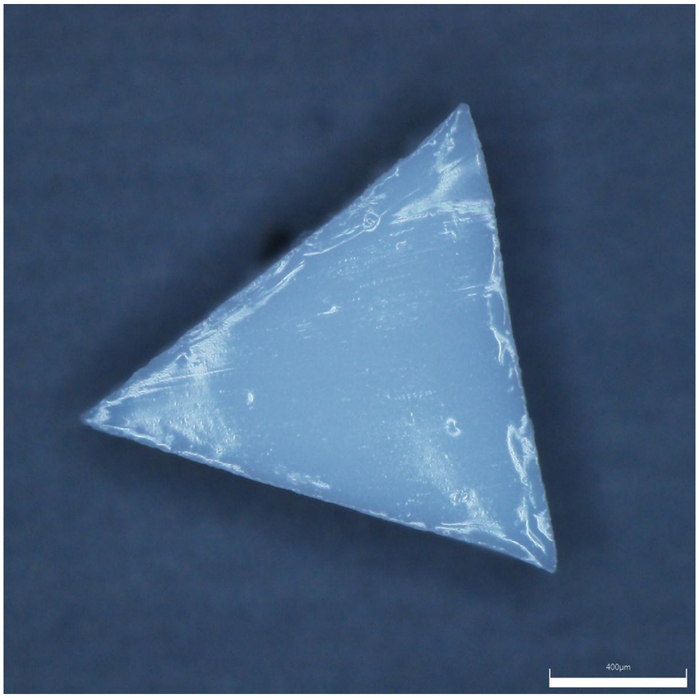

FIG. 13

FIG. 14

FIG. 15

FIG. 16

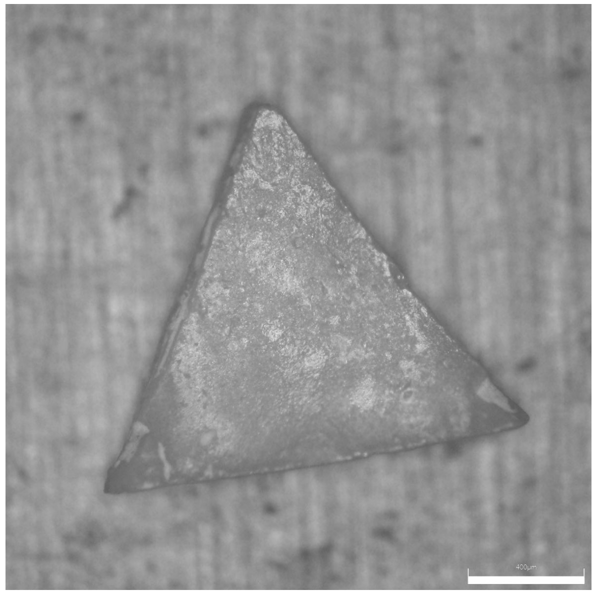

FIG. 17

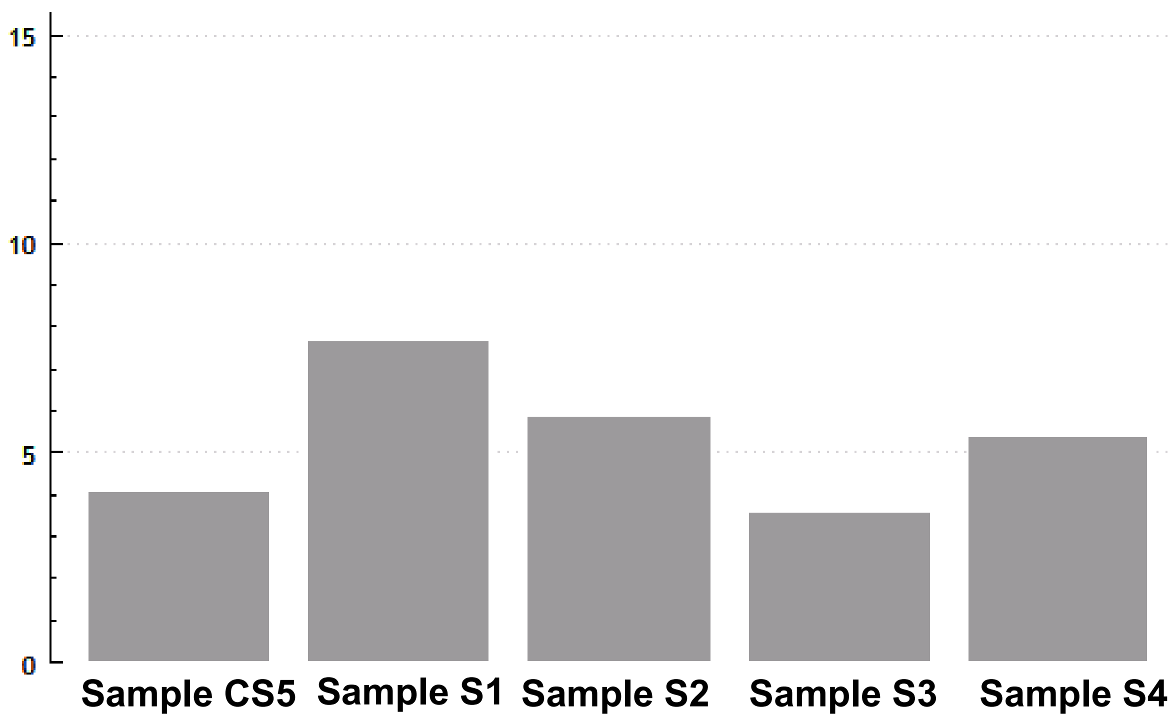

FIG. 18

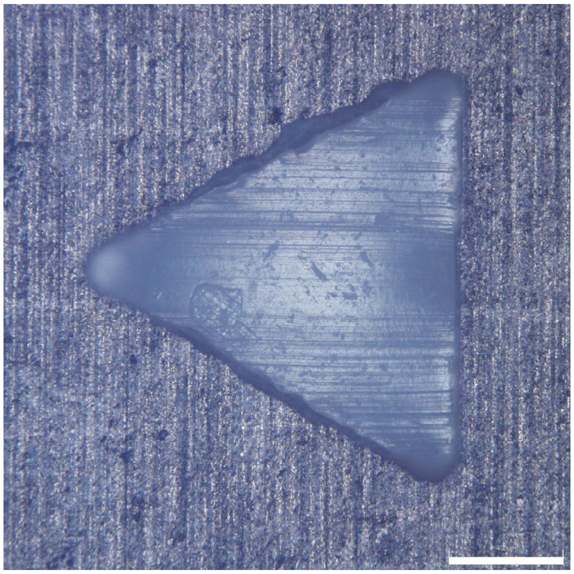

FIG. 19

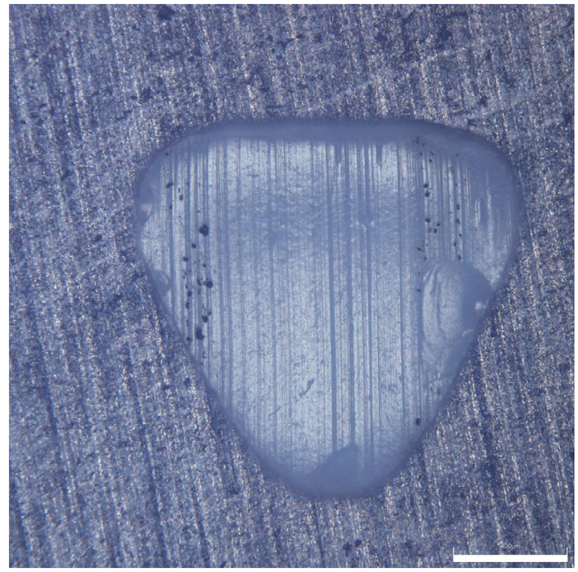

FIG. 20

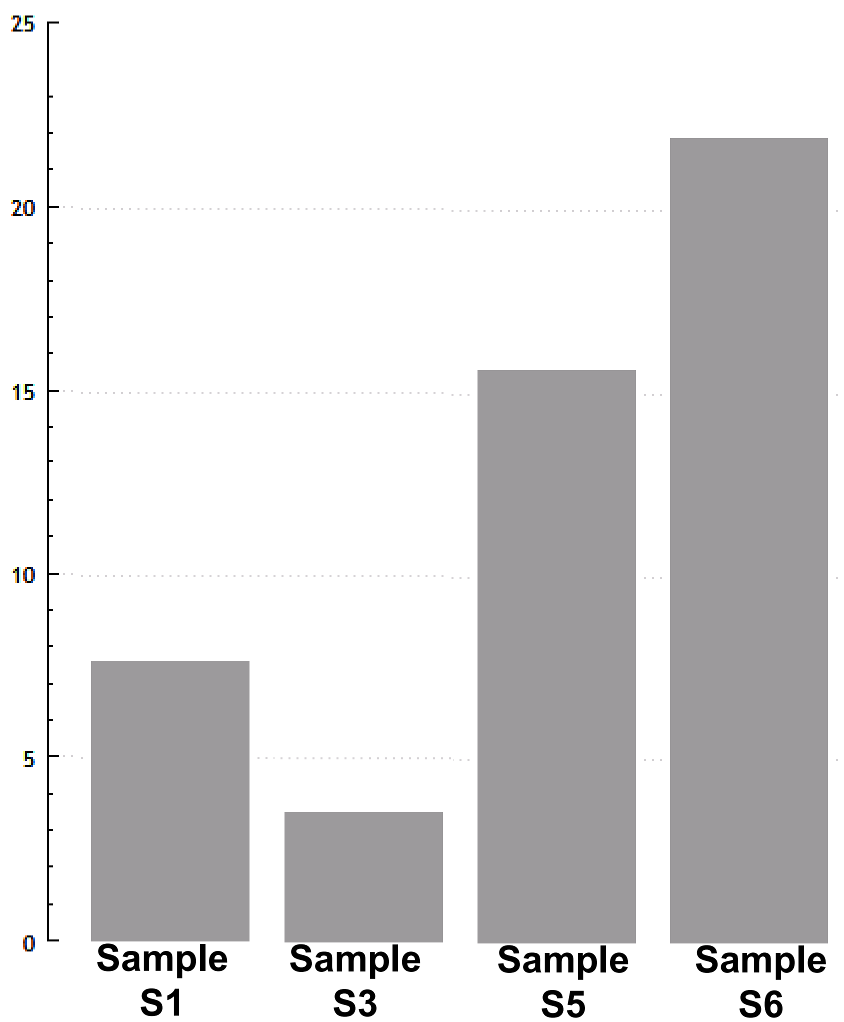

FIG. 21

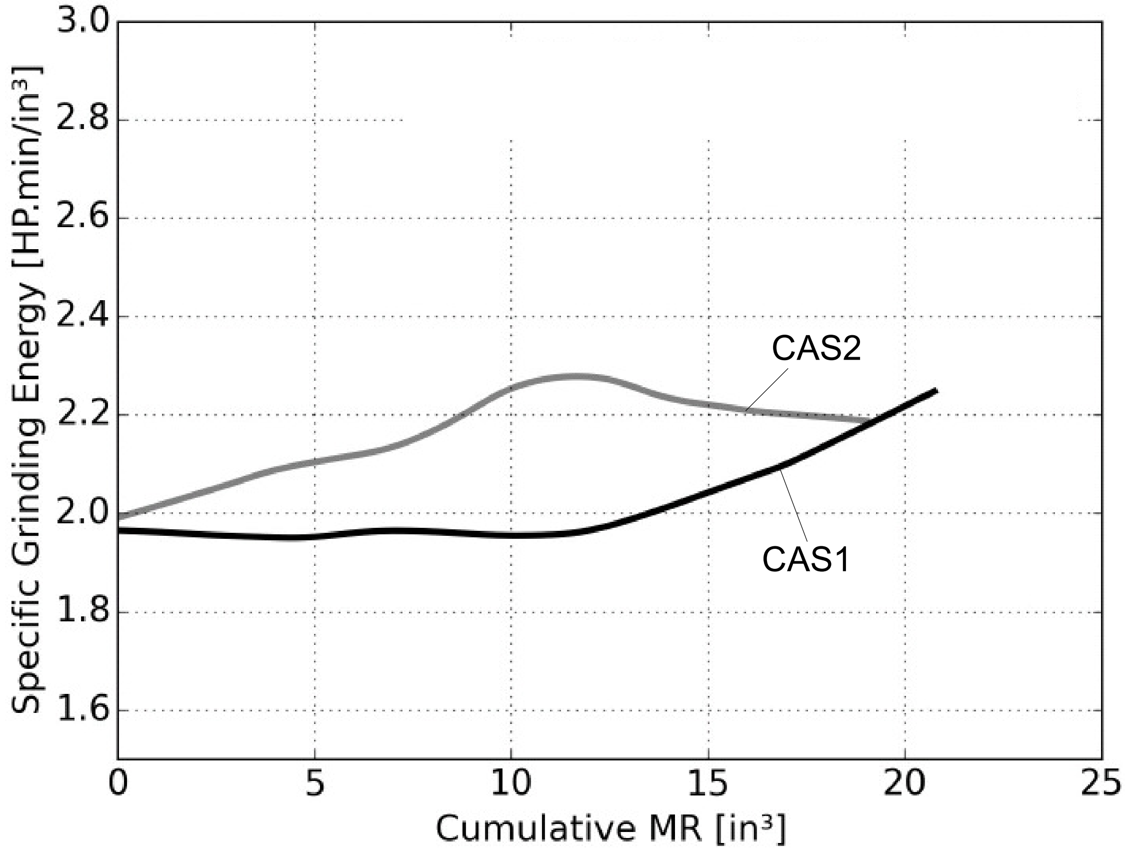
Specific Grinding Energy [HP.min/in³]
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
0
5
10
15
20
25
Cumulative MR [in³]
CAS2
CAS1

FIG. 22

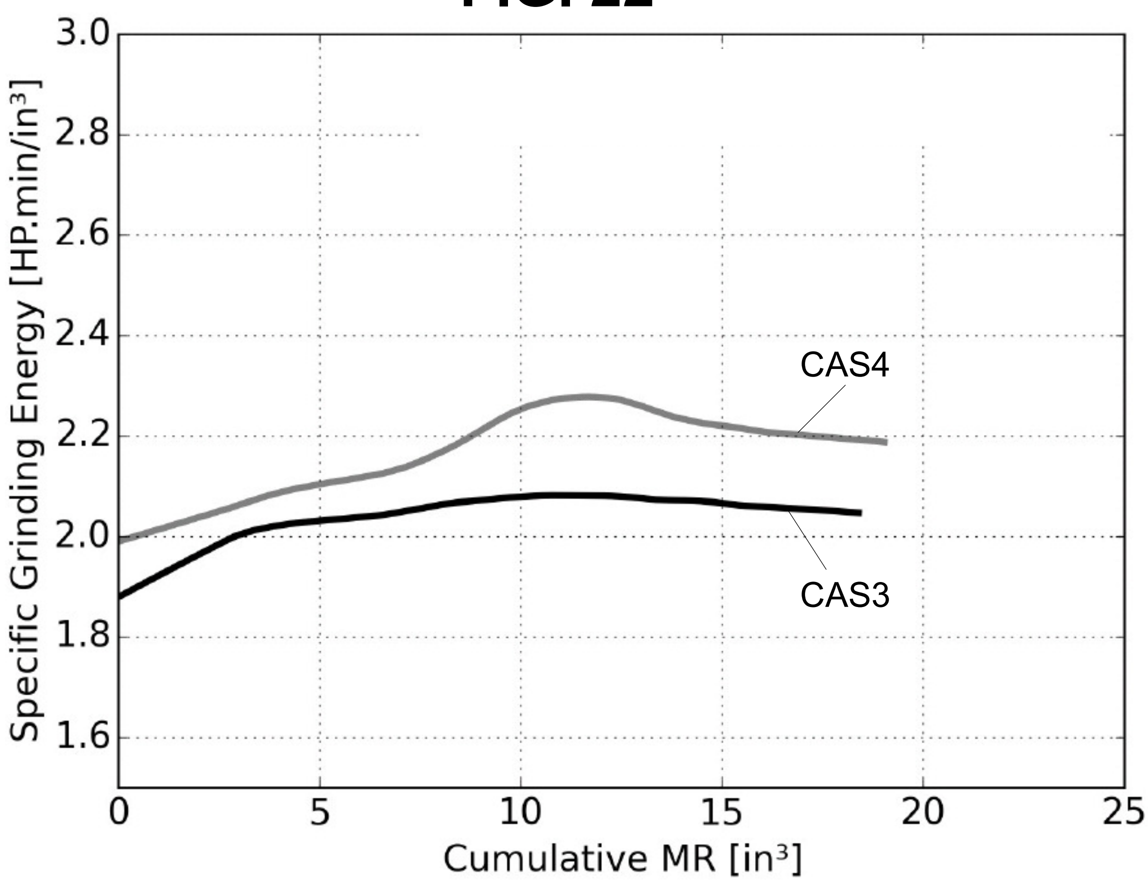
Specific Grinding Energy [HP.min/in³]
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
0
5
10
15
20
25
Cumulative MR [in³]
CAS4
CAS3

FIG. 23