METHOD OF MAKING A COATED ABRASIVE

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ABSTRACT

An abrasive article includes an array of protruding abrasive units. Each unit has a base and a distal apex that is off-center from the base when projected on to a plane that is coplanar with the base. The abrasive article includes a backing bonded to an abrasive coating formed to include the aforementioned abrasive units. Methods for making the abrasive article include nipping a production tool, an abrasive slurry, and the backing. A binder within the slurry is cured during fabrication. The abrasive article may be used to abrade a workpiece.
METHOD OF MAKING A COATED ABRASIVE

FIELD OF THE INVENTION

[0001] This invention pertains to an abrasive array, an abrasive article, a method of making such an abrasive article, and a method of using such an abrasive article. The abrasive article comprises a backing having an abrasive coating bonded to at least one surface of the backing. The abrasive coating is shaped to include protruding units exhibiting useful geometries.

BACKGROUND

[0002] Abrasive articles have been utilized to abrade and finish workpiece surfaces for well over a hundred years. These applications have ranged from high stock removal, high pressure metal grinding processes to fine polishing of ophthalmic lenses. In general abrasive articles comprise a plurality of abrasive particles bonded either together (e.g., a bonded abrasive or grinding wheel) or to a backing (e.g., a coated abrasive). For a coated abrasive there is typically a single, or sometimes two layers of abrasive particles. Once these abrasive particles are worn, the coated abrasive is essentially worn out and is typically discarded.

[0003] A structured abrasive is taught by U.S. Pat. No. 5,152,917 (Pieper et al.). Importantly, the structured abrasive taught by Pieper results in a relatively high rate of cut and a relatively fine surface finish on the workpiece surface. The structured abrasive comprises non-random, precisely shaped abrasive composites that are bonded to a backing.

[0004] Although structured abrasives, such as the one taught by Pieper exhibit desirable characteristics, such as a high cut rate, structured abrasives still tend to lose their effectiveness over time. Thus, a structured abrasive may yield a particular cut rate (expressed, for example, in grams per cycle) in its initial three or four cycles of abrasion, but may yield a cut rate of only a fraction of its initial value after 5 or 10 cycles. Such deterioration in cut rate is inimical to the goal of providing efficient abrasion technology.

[0005] As is evident from the foregoing, there exists a need for a scheme by which a structured abrasive may be made to prolong its life span and minimize its cut rate deterioration.

SUMMARY

[0006] This invention pertains to an abrasive array, an abrasive article, a method of making an abrasive article and a method of using an abrasive article. According to one embodiment of the present invention, a method of making a coated abrasive article may include introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a production tool. The production tool is shaped to include a plurality of protruding units distributed in two dimensions. Each protruding unit has a base that has a periphery. For each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, defines an offset vector between the projection of the distal region and a center point of the base. The offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero. The method may further include introducing a backing to the outer surface of the production tool such that the slurry wets one side of the backing to form an intermediate article. The method may further include at least partially curing or gelling the binder before the intermediate article departs from the outer surface of the production tool to form a coated abrasive article. Finally, the method may include removing the coated abrasive article from the production tool.

[0007] According to another embodiment, a method of abrading a surface of a workpiece may include providing a coated abrasive article comprising a backing having attached to at least one major surface thereof a plurality of abrasive composites. The abrasive composites include a plurality of protruding units distributed in two dimensions. Each protruding unit has a base that has a periphery. For each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, defines an offset vector between the projection of the distal region and a center point of the base. The offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero. The method further includes placing the surface of said article having abrasive composites attached thereto in contact with the surface of said workpiece. Finally, the method further includes moving at least one of the surfaces of said article or the surface of said workpiece with respect to the other so as to abrade the surface of said workpiece.

[0008] According to another embodiment, a method of making a coated abrasive article may include introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a surface of a backing. The method may further include introducing a production tool to the surface of the backing on which the slurry has been introduced to form an intermediate article. The production tool is shaped to include a plurality of protruding units distributed in two dimensions. Each protruding unit has a base that has a periphery. For each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, defines an offset vector between the projection of the distal region and a center point of the base. The offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero. The method further includes at least partially curing or gelling the binder before the intermediate article departs from the production tool to form a coated abrasive article. Finally, the method further includes removing the coated abrasive article from the production tool.

[0009] According to another embodiment, a method of making a coated abrasive article may include introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a production tool. The production tool is shaped to include a plurality of protruding units distributed in two dimensions. Each protruding unit has a base that has a periphery. For each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, defines an offset vector between the projection of the distal region and a center point of the base. The offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero. The method may further include introducing a backing to the outer surface of the production tool such that the slurry wets one side of the backing to form an intermediate article. The method may further include removing the intermediate article from the production tool. Finally, the method may further include curing or gelling the binder to form a coated abrasive article.
[0010] According to yet another embodiment, a method of making a coated abrasive may include introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a surface of a backing. The method may further include introducing a production tool to the surface of the backing on which the slurry has been introduced to form an intermediate article. The production tool is shaped to include a plurality of protruding units distributed in two dimensions. Each protruding unit has a base that has a periphery. For each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, defines an offset vector between the projection of the distal region and a center point of the base. The offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero. The method may further include removing the intermediate article from the production tool. Finally, the method may include curing or gelling the binder to form a coated abrasive article.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a section view, enlarged, representing another abrasive article embodiment of this invention;
[0012] FIG. 2 is a schematic of a process of making the abrasive article of FIG. 1; and
[0013] FIG. 3 is a schematic of another process of making the abrasive article of FIG. 1.
[0014] FIG. 4A depicts a top view of a protruding unit in accordance with an embodiment of the present invention.
[0015] FIG. 4B depicts a top view of a protruding unit in accordance with an embodiment of the present invention.
[0016] FIG. 4C depicts a top view of an abrasive article in accordance with an embodiment of the present invention.
[0017] FIG. 4D depicts another top view of an abrasive article in accordance with an embodiment of the present invention.
[0018] FIG. 4E depicts another top view of a protruding unit in accordance with an embodiment of the present invention.
[0019] FIG. 4F depicts another top view of a protruding unit in accordance with an embodiment of the present invention.
[0020] FIG. 4G depicts another top view of a protruding unit in accordance with an embodiment of the present invention.
[0021] FIG. 4H depicts another top view of a protruding unit in accordance with an embodiment of the present invention.
[0022] FIG. 5 depicts another abrasive article in accordance with an embodiment of the present invention.
[0023] FIG. 6A depicts an array of protruding units in accordance with an embodiment of the present invention.
[0024] FIG. 6B depicts another array of protruding units in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0025] This invention pertains to an abrasive array, an abrasive article, a method of making an abrasive article and a method of using an abrasive article.

[0026] Referring to FIG. 1, the abrasive article 20 comprises abrasive composites 22 separated by boundary 25. The abrasive composites are bonded to a surface of a backing 21. The boundary or boundaries associated with the composite shape result in one abrasive composite being separated to some degree from another adjacent abrasive composite. To form an individual abrasive composite, a portion of the boundaries forming the shape of the abrasive composite must be separated from one another. Note that in FIG. 2, the base or a portion of the abrasive composite closest to the backing can abut with its neighboring abrasive composite. Abrasive composites 22 comprise a plurality of abrasive particles 24 that are dispersed in a binder 23 and a grinding aid 26. It is also within the scope of this invention to have a combination of abrasive composites bonded to a backing in which some of the abrasive composites abut, while other abrasive composites have open spaces between them.

[0027] Backing

[0028] The backing of this invention has a front and back surface and can be any conventional abrasive backing. Examples of useful backings include polymeric film, primed polymeric film, cloth, paper, vulcanized fiber, nonwovens, and combinations thereof. Other useful backings include a fibrous reinforced thermoplastic backing as disclosed in U.S. Pat. No. 5,316,812 and an endless seamless backing as disclosed in World Patent Application No. WO 93/12911 published. The backing may also contain a treatment or treatments to seal the backing and/or modify some physical properties of the backing. These treatments are well known in the art.

[0029] The backing may also have an attachment means on its back surface to enable securing the resulting coated abrasive to a support pad or back-up pad. This attachment means can be a pressure sensitive adhesive, one surface of a hook and loop attachment system, or a threaded projection as disclosed in the above-mentioned U.S. Pat. No. 5,316,812. Alternatively, there may be an intermeshing attachment system as described in the assignee’s U.S. Pat. No. 5,201,101 incorporated herein after by reference.

[0030] The back side of the abrasive article may also contain a slip resistant or frictional coating. Examples of such coatings include an inorganic particle (e.g., calcium carbonate or quartz) dispersed in an adhesive.

[0031] Abrasive Coating

[0032] Abrasive Particles

[0033] The abrasive particles typically have a particle size ranging from about 0.1 to 1500 micrometers, usually between about 0.1 to 400 micrometers, preferably between 0.1 to 100 micrometers and most preferably between 0.1 to 50 micrometers. It is preferred that the abrasive particles have a Moht's hardness of at least about 8, more preferably above 9. Examples of such abrasive particles include fused aluminum oxide (which includes brown aluminum oxide, heat treated aluminum oxide and white aluminum oxide), ceramic aluminum oxide, green silicon carbide, silicon carbide, chromia, alumina zirconia, diamond, iron oxide, ceria, cubic boron nitride, boron carbide, garnet and combinations thereof.

[0034] The term “abrasive particle” also encompasses when single abrasive particles are bonded together to form
an abrasive agglomerate. Abrasive agglomerates are further described in U.S. Pat. Nos. 4,311,489; 4,652,275 and 4,799,939 incorporated herein by reference.

[0035] It is also within the scope of this invention to have a surface coating on the abrasive particles. The surface coating may have many different functions. In some instances the surface coatings increase adhesion of abrasive particles to the binder, alter the abrading characteristics of the abrasive particle, and the like. Examples of surface coatings include coupling agents, halide salts, metal oxides including silica, refractory metal nitrides, refractory metal carbides and the like.

[0036] In the abrasive composite there may also be diluent particles. The particle size of these diluent particles may be on the same order of magnitude as the abrasive particles. Examples of such diluent particles include gypsum, marble, limestone, flint, silica, glass bubbles, glass beads, aluminum silicate, and the like.

[0037] Binder

[0038] The abrasive particles are dispersed in an organic binder to form the abrasive composite. The binder is derived from a binder precursor which comprises an organic polymerizable resin. During the manufacture of the inventive abrasive articles, the binder precursor is exposed to an energy source which aids in the initiation of the polymerization or curing process. Examples of energy sources include thermal energy and radiation energy, the latter including electron beam, ultraviolet light, and visible light. During this polymerization process, the resin is polymerized and the binder precursor is converted into a solidified binder. Upon solidification of the binder precursor, the abrasive coating is formed. The binder in the abrasive coating is also generally responsible for adhering the abrasive coating to the backing.

[0039] There are two preferred classes of resins for use in the present invention, condensation curable and addition polymerizable resins. The preferred binder precursors comprise additional polymerizable resins because these resins are readily cured by exposure to radiation energy. Addition polymerizable resins can polymerize through a cationic mechanism or a free radical mechanism. Depending upon the energy source that is utilized and the binder precursor chemistry, a curing agent, initiator, or catalyst is sometimes preferred to help initiate the polymerization.

[0040] Examples of typical and preferred organic resins include phenolic resins, urea-formaldehyde resins, melamine formaldehyde resins, acrylated ureas, acrylated epoxies, ethylenically unsaturated compounds, aminoplast derivatives having pendant unsaturated carbonyl groups, isocyanate derivatives having at least one pendant acrylate group, isocyanate derivatives having at least one pendant acrylate group, vinyl ethers, epoxy resins, and mixtures and combinations thereof. The term “acrylate” encompasses acrylates and methacrylates.

[0041] Phenolic resins are widely used in abrasive article binders because of their thermal properties, availability, and cost. There are two types of phenolic resins, resole and novolac. Resole phenolic resins have a molar ratio of formaldehyde to phenol of greater than or equal to one to one, typically between 1.5:1.0 to 3.0:1.0. Novolac resins have a molar ratio of formaldehyde to phenol of less than one to one. Examples of commercially available phenolic resins include those known by the tradenames “Durez” and “Vacurem” from Occidental Chemicals Corp.; “Resinox” from Monsanto; “Aerofene” from Ashland Chemical Co. and “Aerotap” from Ashland Chemical Co.

[0042] Acrylated urethanes are diacylate esters of hydroxy-terminated, isocyanate NCO extended polyesters or polyethers. Examples of commercially available acrylated urethanes include those known under the trade designations “UVITHANE 782”, available from Morton Thiokol Chemical, and “CMD 6600”, “CMD 8400”, and “CMD 8805”, available from Radcure Specialties.

[0043] Acrylated epoxies are diacylate esters of epoxy resins, such as the diacylate esters of diglycidyl ether of bisphenol A epoxy resin. Examples of commercially available acrylated epoxies include those known under the trade designations “CMD 3500”, “CMD 3600”, and “CMD 3700”, available from Radcure Specialties.

[0044] Ethylenically unsaturated resins include both monomeric and polymeric compounds that contain atoms of carbon, hydrogen, and oxygen, and optionally, nitrogen and the halogens. Oxygen or nitrogen atoms or both are generally present in ether, ester, urethane, amide, and urea groups.

[0045] Ethylenically unsaturated compounds preferably have a molecular weight of less than about 4,000 and are preferably esters made from the reaction of compounds containing aliphatic monohydroxy groups or aliphatic polyhydroxy groups and unsaturated carboxylic acids, such as acrylic acid, methacrylic acid, itaconic acid, crotonic acid, isocrotonic acid, maleic acid, and the like. Representative examples of acrylic resins include methyl methacrylate, ethyl methacrylate styrene, divinylbenzene, vinyl toluene, ethylene glycol diacrylate, ethylene glycol methacrylate, hexanediol diacrylate, triethylene glycol diacrylate, trimethylolpropane triacylate, glycerol triacylate, pentaerythritol triacylate, pentaerythritol methacrylate, pentaerythritol tetraacrylate and pentaerythritol tetraacrylate. Other ethylenically unsaturated resins include monoallyl, polyallyl, and polymethallyl esters and amides of carboxylic acids, such as diallyl phthalate, diallyl adipate, and N,N-diallylalkylamine. Still other nitrogen containing compounds include tris(2-acryloyloxyethyl)isocyanurate, 1,3,5-tri(2-methacryloxyethyl)-triazine, acrylamide, methacrylamide, N-methacrylamide, N,N-dimethylacrylamide, N-vinylpyrrolidone, and N-vinylpyrrolidone.

[0046] The aminoplast resins have at least one pendant alpha, betaunsaturated carbonyl group per molecule or oligomer. These unsaturated carbonyl groups can be acrylate, methacrylate, or acrylamide type groups. Examples of such materials include N-(hydroxymethyl)acrylamide, N,N'-oxydimethylenebisacrylamide, ortho and para acrylamidomethylated phenol, acrylamidomethylated phenolic novolac, and combinations thereof. These materials are further described in U.S. Pat. Nos. 4,903,440 and 5,236,472 both incorporated herein by reference.

[0047] Isocyanurate derivatives having at least one pendant acrylate group and isocyanate derivatives having at least one pendant acrylate group are further described in U.S. Pat. No. 4,652,274 incorporated herein after by reference. The preferred isocyanate material is a triacylate of tris(hydroxy ethyl) isocyanurate.
Epoxy resins have an oxirane and are polymerized by the ring opening. Such epoxide resins include monomeric epoxy resins and oligomeric epoxy resins. Examples of some preferred epoxy resins include 2,2-bis(4-(2,3-epoxypropoxy)-phenyl propane) (diglycidyl ether of bisphenol) and commercially available materials under the trade designations "Epon 828", "Epon 1004", and "Epon 1001F" available from Shell Chemical Co., "DER-331", "DER-332", and "DER-334" available from Dow Chemical Co. Other suitable epoxy resins include glycidyl ethers of phenol formaldehyde novolac (e.g., "DEN-431" and "DEN-428" available from Dow chemical Co.).

The epoxy resins of the invention can polymerize via a cationic mechanism with the addition of an appropriate cationic curing agent. Cationic curing agents generate an acid source to initiate the polymerization of an epoxy resin. These cationic curing agents can include a salt having an anion cation and a halogen containing a complex anion of a metal or metalloid. Other cationic curing agents include a salt having an organometallic complex cation and a halogen containing complex anion of a metal or metalloid which are further described in U.S. Pat. No. 4,751,138 incorporated here in after by reference (column 6, line 65 to column 9, line 45). Another example is an organometallic salt and an anion salt is described in U.S. Pat. No. 4,985,340 (column 4, line 65 to column 14, line 50); and European Patent Application Nos. 306,161 and 306,162, both published Mar. 8, 1989, all incorporated by reference. Still other cationic curing agents include an ionic salt of an organometallic complex in which the metal is selected from the elements of Periodic Group VII, VB, VIB, VIIB, and VIIIB which is described in European Patent Application No. 109,581, published Nov. 21, 1983, incorporated by reference.

Regarding free radical curable resins, in some instances it is preferred that the abrasive slurry further comprise a free radical curing agent. However in the case of an electron beam energy source, the curing agent is not always required because the electron beam itself generates free radicals.

Examples of free radical thermal initiators include peroxides, e.g., benzoyl peroxide, azo compounds, benzophenones, and quinones. For either ultraviolet or visible light energy source, this curing agent is sometimes referred to as a photoinitiator. Examples of initiators, that when exposed to ultraviolet light generate a free radical source, include but are not limited to those selected from the group consisting of organic peroxides, azo compounds, quinones, benzophenones, nitroso compounds, acryl halides, hydrozones, mercapto compounds, pyrylium compounds, triacylumidazoles, bisimidazoles, chloronalkytrazines, benzoin ethers, benzal ketals, thioxanthones, and acetophenone derivatives, and mixtures thereof. Examples of initiators that when exposed to visible radiation generate a free radical source, can be found in U.S. Pat. No. 4,735,632, entitled Coated Abrasive Binder Containing Ternary Photoinitiator System, incorporated herein by reference. The preferred initiator for use with visible light is "Irgacure 369" commercially available from Ciba Geigy Corporation.

Grinding Aid

A grinding aid is defined as a material, preferably a particulate material, the addition of which to an abrasive article has a significant effect on the chemical and physical processes of abrading which results in improved performance. Typically and preferably the grinding aid is added to the slurry as a particulate, however it may be added to the slurry as a liquid. The presence of the grinding aid will increase the grinding efficiency or cut rate (defined as weight of work piece removed per weight of abrasive article lost) of the corresponding abrasive article in comparison to an abrasive article that does not contain a grinding aid. In particular, it is believed in the art that the grinding aid will either 1) decrease the friction between the abrasive grains and the workpiece being abraded, 2) prevent the abrasive grain from "capping", i.e., prevent metal particles (in the case of a metal workpiece) from becoming welded to the tops of the abrasive grains, 3) decrease the interface temperature between the abrasive grains and the workpiece, 4) decreases the grinding force required, or 5) prevents oxidation of the metal workpiece. In general, the addition of a grinding aid increases the useful life of the abrasive article.
grinding aid in the abrasive coating is increased, the relative amount of abrasive particles is decreased. The abrasive particles are responsible for cutting the workpiece surface, not the grinding aid. In general, the abrasive coating comprises from 5 to 90% by weight, preferably from 20 to 80% by weight abrasive particles, from 5 to 80% by weight, preferably from 5 to 40% by weight binder, and from 5 to 60% by weight, preferably from 10 to 40% by weight grinding aid.

[0059] Optional Additives

[0060] slurries useful in the invention may further comprise optional additives such as, for example, fillers, fibers, lubricants, wetting agents, thixotropic materials, surfactants, pigments, dyes, antistatic agents, coupling agents, plasticizers, and suspending agents. The amounts of these materials are selected to provide the properties desired. The use of these can affect the erodability of the abrasive composite. In some instances an additive is purposely added to make the abrasive composite more erodable, thereby expelling dulled abrasive particles and exposing new abrasive particles.

[0061] Examples of antistatic agents useful in the invention include graphite, carbon black, vanadium oxide, humectants, and the like. These antistatic agents are disclosed in U.S. Pat. Nos. 5,161,204; 5,137,542, and 5,203,884 incorporated herein after by reference.

[0062] A coupling agent can provide an association bridge between the binder precursor and the filler particles or abrasive particles. Examples of useful coupling agents include silanes, titanates, and zirconiumates. Useful slurries preferably contain from about 0.01 to 3% by weight coupling agent.

[0063] An example of a suspending agent useful in the invention is an amorphous silica particle having a surface area less than 150 meters square/gram which is commercially available from DeGussa Corp., under the trade name “OX-50”.

[0064] Abrasive Coating Comprising Abrasive Composites

[0065] In one preferred aspect of the invention, the abrasive coating is in the form of a plurality of abrasive composites bonded to the backing. It is generally preferred that each abrasive composite have a precise shape. The precise shape of each composite is determined by distinct and discernible boundaries. These distinct and discernible boundaries are readily visible and clear when a cross section of the abrasive article is examined under a microscope such as a scanning electron microscope. In comparison, in an abrasive coating comprising composites that do not have precise shapes, the boundaries are not definitive and may be illegible. These distinct and discernible boundaries form the outline or contour of the precise shape. These boundaries separate to some degree one abrasive composite from another and also distinguish one abrasive composite from another.

[0066] Referring to FIG. 1, the abrasive article 10 comprises abrasive composites 22 separated by boundary 25. The boundary or boundaries associated with the composite shape result in one abrasive composite being separated to some degree from another adjacent abrasive composite. To form an individual abrasive composite, a portion of the boundaries forming the shape of the abrasive composite must be separated from one another. Note that in FIG. 1, the base or a portion of the abrasive composite closest to the backing can abut with its neighboring abrasive composite. Abrasive composites 22 comprise a plurality of abrasive particles 24 that are dispersed in a binder 23 and a grinding aid 26. It is also within the scope of this invention to have a combination of abrasive composites bonded to a backing in which some of the abrasive composites abut, while other abrasive composites have open spaces between them.

[0067] In some instances the boundaries forming the shape are planar. For shapes that have planes, there are at least three planes. The number of planes for a given shape can vary depending upon the desired geometry, for instance the number of planes can range from three to over 20. Generally, there are between three to ten planes, preferably between three to six planes. These planes intersect to form the desired shape and the angles at which these planes intersect will determine the shape dimensions.

[0068] In another aspect of this invention, a portion of the abrasive composites have a neighboring abrasive composite of a different dimension. In this aspect of the invention, at least 10%, preferably at least 30%, more preferably at least 50% and most preferably at least 60% of the abrasive composites have an adjacent abrasive composite that has a different dimension. These different dimensions can pertain to the abrasive composite shape, angle between planar boundaries or dimensions of the abrasive composite. The result of these different dimensions for neighboring abrasive composites results in an abrasive article that produces a relatively finer surface finish on the workpiece being abraded or refined. This aspect of the invention is further described in the assignee’s co-pending patent application U.S. Ser. No. 08/120,300 filed Sep. 13, 1993.

[0069] The abrasive composite shape can be any shape, but it is preferably a geometric shape such as a rectangle, cone, semicircle, circle, triangle, square, hexagon, pyramid, octagon and the like. Embodiments of preferred shapes are presented below in a section entitled “GEOMETRIES.” An individual abrasive composite shape may be referred to herein as a “protruding unit.” One other shape is a pyramid and the base of this pyramid can be a three or four sided. It is also preferred that the abrasive composite cross sectional surface area decreases away from the backing or decreases along its height. This variable surface area results in a non-uniform pressure as the abrasive composite wears during use. Additionally, during manufacture of the abrasive article, this variable surface area results in easier release of the abrasive composite from the production tool. In general there are at least 5 individual abrasive composites per square cm. In some instances, there may be at least 500 individual abrasive composites/square cm.

[0070] Method of Making The Abrasive Article

[0071] An essential step to make any of the inventive abrasive articles is to prepare the slurry. The slurry is made by combining together by any suitable mixing technique the binder precursor, the grinding aid, the abrasive particles and the optional additives. Examples of mixing techniques include low shear and high shear mixing, with high shear mixing being preferred. Ultrasonic energy may also be utilized in combination with the mixing step to lower the abrasive slurry viscosity. Typically, the abrasive particles
and grinding aid are gradually added into the binder precursor. The amount of air bubbles in the slurry can be minimized by pulling a vacuum during the mixing step. In some instances it is preferred to heat, generally in the range of 30° to 70° C., the slurry to lower the viscosity. It is important the slurry have rheological properties that allow the slurry to coat well and in which the abrasive particles and grinding aid do not settle out of the slurry.

[0072] Energy Source

[0073] After the slurry is coated onto the backing, such as via transfer from a production tool (discussed below), the slurry may be exposed to an energy source to initiate the polymerization of the resin in the binder precursor. Examples of energy sources include thermal energy and radiation energy. The amount of energy depends upon several factors such as the binder precursor chemistry, the dimensions of the abrasive slurry, the amount and type of abrasive particles and the amount and type of the optional additives. For thermal energy, the temperature can range from about 300 to 150° C., generally from 40° to 120° C. The exposure time can range from about 5 minutes to over 24 hours.

[0074] Suitable radiation energy sources include electron beam, ultraviolet light, or visible light. Electron beam radiation, which is also known as ionizing radiation, can be used at an energy level of about 0.1 to about 10 Mrad, preferably at an energy level of about 1 to about 10 Mrad. Ultraviolet radiation refers to non-particle radiation having a wavelength within the range of about 200 to about 400 nanometers, preferably within the range of about 250 to 400 nanometers. Visible radiation refers to non-particle radiation having a wavelength within the range of about 400 to about 800 nanometers, preferably in the range of about 400 to about 550 nanometers. It is preferred that 300 to 600 Watt/inch visible lights are used.

[0075] After this polymerization process is complete, the binder precursor is converted into a binder and the slurry is converted into an abrasive coating. The resulting abrasive article is generally ready for use. However, in some instances other processes may still be necessary such as humidification or flexing. The abrasive article can be converted into any desired form such as a cone, endless belt, sheet, disc, and the like, before the abrasive article is used.

[0076] Production Tool

[0077] Regarding the third and fourth aspects of the invention, in some instances it is preferred that the abrasive coating be present as precisely shaped abrasive composites. In order to make this type of abrasive article, a production tool is generally required.

[0078] The production tool contains a plurality of cavities. These cavities are essentially the inverse shape of the abrasive composite and are responsible for generating the shape of the abrasive composites. The dimensions of the cavities are selected to provide the desired shape and dimensions of the abrasive composites. If the shape of dimensions of the cavities are not properly fabricated, the resulting production tool will not provide the desired dimensions for the abrasive composites.

[0079] The cavities can be present in a dot like pattern with spaces between adjacent cavities or the cavities can butt up against one another. It is preferred that the cavities butt up against one another. Additionally, the shape of the cavities is selected such that the cross-sectional area of the abrasive composite decreases away from the backing.

[0080] The production tool can be a belt, a sheet, a continuous sheet or web, a coating roll such as a rotogravure roll, a sleeve mounted on a coating roll, or die. The production tool can be composed of metal, (e.g., nickel), metal alloys, or plastic. The metal production tool can be fabricated by any conventional technique such as engraving, bobbing, electroforming, diamond turning, and the like. One preferred technique for a metal production tool is diamond turning.

[0081] A thermoplastic can be replicated off a metal master tool. The master tool will have the inverse pattern desired for the production tool. The master tool can be made in the same manner as the production tool. The master tool is preferably made out of metal, e.g., nickel and is diamond turned. The thermoplastic sheet material can be heated and optionally along with the master tool such that the thermoplastic material is embossed with the master tool pattern by pressing the two together. The thermoplastic can also be extruded or cast onto the master tool and then pressed. The thermoplastic material is cooled to solidify and produce the production tool. Examples of preferred thermoplastic production tool materials include polyester, polycarbonates, polyvinyl chloride, polypropylene, polychloroethylene and combinations thereof. If a thermoplastic production tool is utilized, then care must be taken not to generate excessive heat that may distort the thermoplastic production tool.

[0082] The production tool may also contain a release coating to permit easier release of the abrasive article from the production tool. Examples of such release coatings for metals include hard carbide, nitrides or borides coatings. Examples of release coatings for thermoplastics include silicones and fluorochromes.

[0083] One method to make the abrasive article of the invention illustrated in FIG. 2 is illustrated in FIG. 2. Backing 41 leaves an unwind station 42 and at the same time the production tool 46 leaves an unwind station 45. Production tool 46 is coated with slurry by means of coating station 44. It is possible to heat the slurry and/or subject the slurry to ultrasonics prior to coating to lower the viscosity. The coating station can be any conventional coating means such as drop die coater, knife coater, curtain coater, vacuum die coater or a die coater. During coating the formation of air bubbles should be minimized. The preferred coating technique is a vacuum fluid bearing die, such as disclosed in U.S. Pat. Nos. 3,594,865, 4,589,265, and 5,077,870, all incorporated herein by reference. After the production tool is coated, the backing and the slurry are brought into contact by any means such that the slurry wets the front surface of the backing. In FIG. 2, the slurry is brought into contact with the backing by means of contact nip roll 47. Next, contact nip roll 47 also forces the resulting construction against support drum 43. A source of energy 48 (preferably a source of visible light) transmits a sufficient amount of energy into the slurry to at least partially cure the binder precursor. The term partial cure is meant that the binder precursor is polymerized to such a state that the slurry does not flow from an inverted test tube. The binder precursor can be fully cured once it is removed from the production tool by any energy source.
Following this, the production tool is rewound on mandrel 49 so that the production tool can be reused again. Optionally, the production tool may be removed from the binder precursor prior to any curing of the precursor at all. After removal, the precursor may be cured, and the production tool may be rewound on mandrel 49 for reuse. Additionally, abrasive article 120 is wound on mandrel 121. If the binder precursor is not fully cured, the binder precursor can then be fully cured by either time and/or exposure to an energy source. Additional steps to make abrasive articles according to this first method are further described in U.S. Pat. No. 5,152,917 and U.S. Ser. No. 08/004,929, filed Jan. 14, 1993, both incorporated herein by reference. Randomly shaped abrasives composites may be made by the tooling and procedures described in copending Ser. No. 08/120,300, filed Sep. 13, 1993, incorporated herein by reference.

[0084] It is preferred that the binder precursor is cured by radiation energy. The radiation energy can be transmitted through the production tool so long as the production tool does not appreciably absorb the radiation energy. Additionally, the radiation energy source should not appreciably degrade the production tool. It is preferred to use a thermoplastic production tool and ultraviolet or visible light.

[0085] The slurry can be coated onto the backing and not into the cavities of the production tool. The slurry coated backing is then brought into contact with the production tool such that the slurry flows into the cavities of the production tool. The remaining steps to make the abrasive article are the same as detailed above.

[0086] Another method is illustrated in FIG. 3. Backing 51 leaves an unwind station 52 and the slurry 54 is coated into the cavities of the production tool 55 by means of the coating station 53. The slurry can be coated onto the tool by any one of many techniques such as drop die coating, roll coating, knife coating, curtain coating, vacuum die coating, or die coating. Again, it is possible to heat the slurry and/or subject the slurry to ultrasonics prior to coating to lower the viscosity. During coating the formation of air bubbles should be minimized. Then, the backing and the production tool containing the abrasive slurry are brought into contact by a nip roll 56 such that the slurry wets the front surface of the backing. Next, the binder precursor in the slurry is at least partially cured by exposure to an energy source 57. After this at least partial cure, the slurry is converted to an abrasive composite 59 that is bonded or adhered to the backing. The resulting abrasive article is removed from the production tool by means of nip rolls 58 and wound onto a rewind station 60. Optionally, the production tool may be removed from the binder precursor prior to any curing of the precursor at all. After removal of the production tool, the precursor may be cured. In either event, the energy source can be thermal energy or radiation energy. If the energy source is either ultraviolet light or visible light, it is preferred that the backing be transparent to ultraviolet or visible light. An example of such a backing is polyester backing.

[0087] The slurry can be coated directly onto the front surface of the backing. The slurry coated backing is then brought into contact with the production tool such that the slurry wets into the cavities of the production tool. The remaining steps to make the abrasive article are the same as detailed above.

[0088] Method of Refining a Workpiece Surface

[0089] Another aspect of this invention pertains to a method of abrading a metal surface. This method involves bringing into frictional contact the abrasive article of this invention with a workpiece having a metal surface. The term “abrating” means that a portion of the metal workpiece is cut or removed by the abrasive article. Additionally, the surface finish associated with the workpiece surface is typically reduced after this refining process. One typical surface finish measurement is Ra; Ra is the arithmetic surface finish generally measured in microinches or micrometers. The surface finish can be measured by a profilometer, such as a Perfhometer or Surtronic.

[0090] Workpiece

[0091] The metal workpiece can be any type of metal such as mild steel, stainless steel, titanium, metal alloys and the like. The workpiece may be flat or may have a shape or contour associated with it.

[0092] Depending upon the application, the force at the abrating interface can range from about 0.1 kg to over 1000 kg. Generally this range is from 1 kg to 500 kg of force at the abrating interface. Also depending upon the application, there may be a liquid present during abrating. This liquid can be water and/or an organic compound. Examples of typical organic compounds include lubricants, oils, emulsified organic compounds, cutting fluids, soaps, or the like. These liquids may also contain other additives such as defoamers, degreasers, corrosion inhibitors, or the like. The abrasive article may oscillate at the abrating interface during use. In some instances, this oscillation may result in a finer surface on the workpiece being abraded.

[0093] The abrasive articles of the invention can be used by hand or used in combination with a machine. At least one or both of the abrasive article and the workpiece is moved relative to the other during grinding. The abrasive article can be converted into a belt, tape roll, disc, sheet, and the like. For belt applications, the two free ends of an abrasive sheet are joined together and a splice is formed. It is also within the scope of this invention to use a spliceless belt like that described in the assignee’s co-pending patent application U.S. Ser. No. 07/919,541, filed Jul. 24, 1992, incorporated herein after by reference. Generally the endless abrasive belt traverses over at least one idler roll and a platen or contact wheel. The hardness of the platen or contact wheel is adjusted to obtain the desired rate of cut and workpiece surface finish. The abrasive belt speed depends upon the desired cut rate and surface finish. The belt dimensions can range from about 5 mm to 1,000 mm wide and from about 5 mm to 10,000 mm long. Abrasive tapes are continuous lengths of the abrasive article. They can range in width from about 1 mm to 1,000 mm, generally between 5 mm to 250 mm. The abrasive tapes are usually unwound, traverse over a support pad that forces the tape against the workpiece and then rewound. The abrasive tapes can be continuously fed through the abrating interface and can be indexed. The abrasive disc can range from about 50 mm to 1,000 mm in diameter. Typically abrasive discs are secured to a back-up pad by an attachment means. These abrasive discs can rotate between 100 to 20,000 revolutions per minute, typically between 1,000 to 15,000 revolutions per minute.
Geometries

As alluded to in the section of this disclosure entitled “ABRASIVE COATING COMPRISING ABRASIVE COMPOSITES,” the abrasive composites may be shaped into units that protrude from the backing to which they are bonded. The individual shaped composite abrasives are referred to herein as “protruding units.” The particular geometry chosen for the protruding units may impact the performance of the structured abrasive article in which they are situated. The geometry schemes presented below are chosen to provide elevated initial cut rates (as measured in mass per cycle) and to exhibit minimal deterioration in cut rates with each successive abrasion cycle.

The protruding units shown in FIGS. 4A-H, 5, and 6A and 6B, and the other protruding units discussed herein may be structured from materials described above, making use of fabrication methods described above. Although FIGS. 4A-H, 5, and 6A and 6B do not depict abrasive grains and binder within the protruding units, it is understood that such grains and binder exist, as the protruding units have abrasive grains and binder as a constituent material.

FIG. 4A depicts a top view of a protruding unit 400. The protruding unit has a base 401, which is in the shape of a square. Other than the base 401, the protruding unit 400 has four sides, which extend from each of the various sides of the base 401 to a linear apex 406. Due to the perspective of FIG. 4A, only sides 403 and 405 are visible.

As can be seen from FIG. 4A, the linear apex 406, when projected on to a plain that is coplanar with the base 401, extends between oppositely disposed sides of the base 401. When referring to the projection of an apex, such as apex 406, on to a plain that is coplanar with a base of a protruding unit, the terms “projection of the apex” or “projection of the linear apex” may be used herein. The center points of the oppositely disposed sides between which the projection of the linear apex 406 extends are identified with small hashings. The projection of the linear apex 406 does not extend between the center points of the oppositely disposed sides.

The protruding unit of FIG. 4A may be arranged into a two-dimensional array, as shown in FIG. 4B. FIG. 4B depicts an array of substantially identical protruding units 400 disposed such that the base of each protruding unit 400 abuts the base of an adjacent protruding unit 400. The protruding units 400 are shown as being bonded to a backing 408, creating an abrasive article. Although the array depicted in FIG. 4B is shown as being two-by-two, the array may be of any size in principle. Furthermore, as shown in FIG. 4C, the array may be constructed so that the bases of adjacent protruding units 400 do not abut one another.

FIG. 4D depicts a protruding unit 410. As can be seen therein, the protruding unit has a linear apex 412 that has a length that is insufficient for its projection to extend from one side of the base 414 to the other. Thus, each of the sides tapers inwardly from the base 414 toward the distal linear apex. Notably, if the projection of the linear apex 412 is extrapolated, its extrapolation does not meet with a center point of either oppositely disposed side of the base 414. In this way, it can be said that the projection of the linear apex 412 does not extend “between” center points of oppositely disposed sides of the base 414.

FIG. 4E depicts yet another protruding unit 416. The protruding units depicted in FIGS. 4A, 4B, 4C, and 4D exhibit the characteristic that their respective linear apexes 412 do not extend between center points of oppositely disposed sides of their respective bases via employment of a similar scheme: the linear apexes have been askew to all of the sides of their respective bases. As shown in FIG. 4E, the projection of the linear apex 418 may be parallel to some of the sides of the base 420, and yet not extend between center points of oppositely disposed sides of the base 420.

FIG. 4F depicts yet another protruding unit 422. FIG. 4F demonstrates that while the apex of a protruding unit may be linear, it is not essential that it be rectilinear. The protruding unit 422 has a curvilinear (as opposed to rectilinear) apex 424. The projection of the curvilinear apex 424 does not extend between center points of oppositely disposed sides of the base 426.

The bases that have been presented in FIGS. 4A, 4B, 4C, 4D, 4E, and 4F have all been in the shape of a square. Such a restriction is not essential. In principle, the base may be any closed shape. For example, the base may be any regular or irregular polygon, may be a parallelogram, rectangle, or any for of quadrilateral. The base may be circular or elliptical. The sides of the base may be rectilinear or curvilinear. For example, the protruding unit 428 depicted in FIG. 4G has four sides, two of which are curvilinear 430 and 432. The center point of the oppositely disposed curvilinear sides of the base may be found by dividing the curvilinear sides into two segments, wherein the length of the first segment is equal to the length of the second segment. For example, side 430 has been divided into two segments: segments AB and BC. Point B, the center point, is positioned so that the length of segment AB is equal to the length of segment BC. One skilled in the art understands that other measures of centrality may be used to identify the center point of a line that is not rectilinear. Again, the projection of the linear apex 434 extends between oppositely disposed sides 430 and 432, but not at their respective center points.

FIG. 4H depicts a protruding unit 436 that has a base 438 that is in the shape of a pentagon. The center point of side AB is identified with a small hash mark. Notably, protruding unit 436 does not, at first glance, appear to have a side disposed opposite of side AB. For the sake of orienting the linear apex 440 so as to extend between non-central points on oppositely disposed sides of a base, one may consider the side opposite AB to be the compound segment ACDEB. The center point of side ACDEB is point D, because the length of segment AC equals the length of segment DEB. Thus, it is plain to see that linear apex 440 does not extend between center point of oppositely disposed sides of the base 438.

The general principle to be extracted from the discussion associated with FIG. 4H is that a particular scheme can be used to find a side that is disposed opposite a given side of a base. In short, a set of sides that subtends a given side of a base may collectively be considered a single side that is disposed opposite the given side (e.g., side ACDEB subretends side AB, and may be considered to be disposed opposite side AB).

FIG. 5 depicts a perspective view of an abrasive article 500 including a two dimensional array of protruding
units, some of which have been identified with reference numeral 502. Each protruding unit 502 has a base that is rectangular. According to one embodiment of the present invention, the length and width of the base may be between 1 and 150 mils. Each base has a linear apex 504. According to one embodiment of the present invention, the linear apex may be oriented up to 60 mils above the base. Although each of the bases in FIG. 5 is depicted as having the same size and geometry, neither condition is essential. The bases may be of varying size and geometry. Also, although each of the linear apexes 504 is depicted as being parallel with one another, this condition is not essential. The linear apexes 504 may be non-parallel to one another. Finally, although each of the linear apexes is depicted as being a constant distance from their respective bases, this condition is also not essential. The distance between the bases and their respective linear apexes 504 may vary from protruding unit 502 to protruding unit 502.

[0107] FIG. 6A depicts an array of protruding units 600-606. Each of the protruding units 600-606 has an apex 608-614 that is substantially in the shape of a point. Any of the linear apexes in any of the preceding examples may be embodied as a point, as opposed to being embodied as a linear segment. Returning to discussion to FIG. 6A, each of the protruding units 600-606, the apex 608-614 is located remote from the center. The projection of each apex 608-614 defines an offset vector v1, v2, v3, and v4 extending from the center and/or center of mass of the respective base to the projection of the apex 608-614. Notably, the sum of the offset vectors v1, v2, v3, and v4 does not equal zero. For example, assuming that each of the offset vectors v1, v2, v3, and v4 is a unit vector, the sum of the vectors is 2y. For a large array of protruding units, the sum of the offset vectors should not approach a limit of zero as the number of vectors summed together approaches infinity:

\[ \lim_{n \to \infty} \left( \sum_{i=1}^{n} \mathbf{v}_i \right) = 0 \]

[0108] Stated another way, when viewed in totality, the array should exhibit net directability with respect to the positioning of the apexes 608-614.

[0109] FIG. 6B shows the idea of net proportionality as it applies to protruding units having linear apexes 616-622. As can be seen from FIG. 6B, the projection of the linear apexes 616-622 define an offset vector v1, v2, v3, and v4 extending from the centers and/or centers of mass of the respective base to the center of the projection of the apexes 616-622. Once again, for a large array of protruding units, the sum of the offset vectors should not approach a limit of zero as the number of vectors summed together approaches infinity:

\[ \lim_{n \to \infty} \left( \sum_{i=1}^{n} \mathbf{v}_i \right) = 0 \]

[0110] Stated another way, when viewed in totality, the array should exhibit net directability with respect to the positioning of the apexes 608-614.

[0111] Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to the illustrative embodiments set forth herein.

What is claimed is:

1. A method of making a coated abrasive article comprising the steps of:

(a) introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a production tool, wherein the production tool is shaped to include a plurality of protruding units distributed in two dimensions,

(b) introducing a backing to the outer surface of the production tool such that the slurry wets one side of the backing to form an intermediate article;

(c) at least partially curing the binder before the intermediate article departs from the outer surface of the production tool to form a coated abrasive article; and

(d) removing the coated abrasive article from the production tool.

2. The method of claim 1, wherein each distal region is linear.

3. The method of claim 2, wherein each distal region is rectilinear.

4. The method of claim 2, wherein each distal region is curvilinear.

5. The method of claim 1, wherein each base is a parallelogram.

6. The method of claim 5, wherein none of the sides of the parallelogram is parallel to an edge of an article upon which the abrasive array is disposed.

7. The method of claim 1, wherein for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base.

8. The method of claim 1, wherein consecutive bases do not abut.

9. A method of abrading a surface of a workpiece comprising steps of:

(a) providing a coated abrasive article comprising a backing having attached to at least one major surface thereof a plurality of abrasive composites, wherein the abrasive composites include a plurality of protruding units distributed in two dimensions,

(b) wherein each protruding unit has a base that has a periphery,

(c) wherein, for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base, and defines an offset vector between the projection of the distal region and a center point of the base; and

(d) wherein the offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero;
(b) placing the surface of said article having abrasive composites attached thereto in contact with the surface of said workpiece; and

(c) moving at least one of the surface of said article or the surface of said workpiece with respect to the other so as to abrade the surface of said workpiece.

10. The method of claim 9, wherein each distal region is linear.

11. The method of claim 10, wherein each distal linear region is rectilinear.

12. The method of claim 10, wherein each distal linear region is curvilinear.

13. The method of claim 9, wherein each base is a parallelogram.

14. The method of claim 13, wherein none of the sides of the parallelogram is parallel to an edge of an article upon which the abrasive array is disposed.

15. The method of claim 9, wherein for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base.

16. The method of claim 9, wherein consecutive bases do not abut.

17. A method of making a coated abrasive article comprising the steps of:

(a) introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a surface of a backing;

(b) introducing a production tool to the surface of the backing on which the slurry has been introduced to form an intermediate article, wherein the production tool is shaped to include a plurality of protruding units distributed in two dimensions, wherein each protruding unit has a base that has a periphery,

wherein, for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base, and defines an offset vector between the projection of the distal region and a center point of the base; and

wherein the offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero;

(c) at least partially curing the binder before the intermediate article departs from the production tool to form a coated abrasive article; and

(d) removing the coated abrasive article from the production tool.

18. The method of claim 17, wherein each distal region is linear.

19. The method of claim 18, wherein each distal linear region is rectilinear.

20. The method of claim 18, wherein each distal linear region is curvilinear.

21. The method of claim 17, wherein each base is a parallelogram.

22. The method of claim 21, wherein none of the sides of the parallelogram is parallel to an edge of an article upon which the abrasive array is disposed.

23. The method of claim 17, wherein for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base.

24. The method of claim 17, wherein consecutive bases do not abut.

25. A method of making a coated abrasive article comprising the steps of:

(a) introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a production tool, wherein the production tool is shaped to include a plurality of protruding units distributed in two dimensions, wherein each protruding unit has a base that has a periphery,

wherein, for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base, and defines an offset vector between the projection of the distal region and a center point of the base; and

wherein the offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero;

(b) introducing a backing to the outer surface of the production tool such that the slurry wets one side of the backing to form an intermediate article;

(c) removing the intermediate article from the production tool; and

(d) curing the binder to form a coated abrasive article.

26. The method of claim 25, wherein each distal region is linear.

27. The method of claim 26, wherein each distal region is rectilinear.

28. The method of claim 26, wherein each distal region is curvilinear.

29. The method of claim 25, wherein each base is a parallelogram.

30. The method of claim 29, wherein none of the sides of the parallelogram is parallel to an edge of an article upon which the abrasive array is disposed.

31. The method of claim 25, wherein for each unit, its respective distal region, when projected on to a plane that is coplanar with its respective base, falls within the periphery of the base.

32. The method of claim 25, wherein consecutive bases do not abut.

33. A method of making a coated abrasive article comprising the steps of:

(a) introducing a slurry containing a mixture of a binder and a plurality of abrasive grains onto a surface of a backing;

(b) introducing a production tool to the surface of the backing on which the slurry has been introduced to form an intermediate article, wherein the production tool is shaped to include a plurality of protruding units distributed in two dimensions, wherein each protruding unit has a base that has a periphery,
wherein, for each unit, its respective distal region, when projected onto a plane that is coplanar with its respective base, falls within the periphery of the base, and defines an offset vector between the projection of the distal region and a center point of the base; and

wherein the offset vectors for the plurality of protruding units do not exhibit a sum that approaches a limit of zero;

(c) removing the intermediate article from the production tool; and

(d) curing the binder to form a coated abrasive article.

34. The method of claim 33, wherein each distal region is linear.

35. The method of claim 34, wherein each distal region is rectilinear.

36. The method of claim 34, wherein each distal region is curvilinear.

37. The method of claim 33, wherein each base is a parallelogram.

38. The method of claim 37, wherein none of the sides of the parallelogram is parallel to an edge of an article upon which the abrasive array is disposed.

39. The method of claim 33, wherein for each unit, its respective distal region, when projected onto a plane that is coplanar with its respective base, falls within the periphery of the base.

40. The method of claim 33, wherein consecutive bases do not abut.

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