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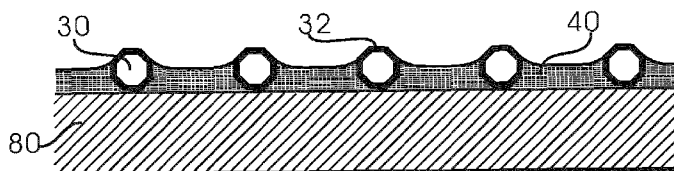


FIG. 1

(57) Abstract: An abrasive article comprising a plurality of abrasive grains that are precisely arranged in accordance with a predetermined pattern and are chemically bonded with a matrix material, and a method for the making thereof are disclosed. A coating layer on each of the abrasive grains functions as a bridge to form chemical bonding between the abrasive grains and the matrix material. In addition to a plated material, the matrix material can include a braze, a solder, a sintered material, an infiltrant, an organic material, and a vitrified material. The method for making the abrasive article comprises the steps of: coating abrasive grains with a coating layer that chemically bonds to each of the abrasive grains; arranging the coated abrasive grains in accordance with a predetermined pattern; and chemically bonding the coated abrasive grains with a matrix material.



ABRASIVE ARTICLE AND METHOD FOR MAKING THE SAME

TECHNICAL FIELD

The present invention relates generally to abrasive articles and processes for producing
5 the same. More particularly, the present invention relates to an abrasive tool which comprises
abrasive grains chemically bonded and precisely arranged in accordance with a predetermined
pattern. Accordingly, the present invention involves the fields of materials science,
mechanical engineering, and physics.

10 BACKGROUND ART

Diamond, the hardest abrasive currently known, is widely used on saws, drills, and
other devices to cut, form, or polish materials such as aluminum, copper, carbide alloy, stone,
concrete, asphalt, glass, ceramics, gem stone, semiconductor materials, rubber and resin,
while the other super abrasive tool, cubic boron nitride (CBN) tool, is suitable to process
15 steels including common steels and various tough alloy steels. According to their
manufacturing methods or bond types, abrasive tools can be categorized into several types,
such as metal-bonded (i.e. sintered product of metal mixture powder and abrasive grains),
resin-bonded, ceramic-bonded tools (i.e. vitreous bond) and electroplated tools.

Despite their practical use in industries, a number of issues continue to hamper the
20 performance and usable life of abrasive tools. For example, grain retention remains
problematic. In most cases, grains are merely mechanically embedded in the matrix material
rather than chemically bonded. As a result, grains are often pulled out prematurely, or the
height of protrusion of grains is compromised, e. g. less than 1/3 to 1/2 of the average
diameter of the particles, resulting in a limited cutting ability. A strong bonding also enables
25 the tools to be used as reciprocating saws which can cut thicker work pieces than circular
saws. By contrast, with a weak bond, reciprocating saws are not as competitive as circular
saws which cut the work piece in one directional movement, causing a "tail" to be formed, i. e.
the matrix material rotationally forward of the diamond particle is worn away, but the matrix
material behind the diamond particle is protected by the diamond particle. Another limitation
30 associated with the conventional abrasive tools is that the grains are not arranged to maximize
efficiency for cutting, drilling, grinding, polishing, etc. In most cases, grains are placed at
random. Generally, a tool having evenly spaced particles wears more evenly, preventing

premature failure of the tool while keeping the amount of expensive abrasive used to a minimum. In some instances, the particles may be deliberately disposed in varied concentration and size distribution patterns to compensate for uneven wear in tools like circular saw blades and disc-shaped grinding tools.

5 Though abrasive tools with abrasive chemically bonded and regularly arranged have been successfully developed by brazing (WO2012/162430, WO2010/141464, US6416560, US6679243 and US8104464), the bonding strength between grains and brazed material is limited because of thermal residual stress induced during cooling period from high brazing temperature; degradation of grain surface (e. g. graphitization of diamond) because of high
10 brazing temperature; and compromises made when selecting material, temperature and equipment for the brazing process. In addition, it is difficult for brazing method to achieve accurate grain positioning pattern and protruding height because of further movement of placed particles following melting of the brazing material. It is also difficult or even impossible for the brazing technique to obtain products with thin blade, high precision and
15 complex shape by means of lower cost.

By contrast, there is no method provided to make an electroplated tool with grains chemically bonded and regularly arranged although products have been reported with a regular abrasive pattern, for example, abrasive tools (WO2004/094111, EP1120196, US2008/0250722 and US2007/0128994), diamond tools comprising concave portions for
20 positioning the diamond particles (US8100997), abrasive tools made with a self-avoiding abrasive grain array (US7993419), CMP pad conditioners (WO1997/009469, KR2012/0011998 and JP4508514), flexible abrasive articles (WO96/26811, CA1280896, CA1317465 and CA1317466), and diamond saw blades (US7178517) comprising multiple equidistant openings for positioning the diamond particles. But no chemical bonding is
25 reported in these tools probably due to the use of naked abrasive grains which have unique surface characteristics (e. g. bad wettability and non-platability of diamond).

It has been proposed in recent years that coated abrasive grains, the surface of which is coated with a layer composed of nickel, titanium or copper, be used in electrodeposited tools, such as dicing blades for cutting wafers into die (WO2012/073854 and US5316559), and wire
30 saws (US2012/0167482, US2012/0017741, WO2011/042931, EP1886753 and JP2005/023877) though the grains are not regularly arranged. In manufacture of an electrodeposited wire tool, abrasive grains are electrodeposited to the core wire by immersing

the core wire in a plating bath containing coated abrasive grains. Because of the high conductivity of the coated grains, metal also begins to deposit on the metal coatings of the abrasive grains, forming an intermetallic bond between the coating and metal deposit. The intermetallic bond is much stronger than mechanical bond between naked grains and metal deposit. But, when other abrasive grains which have fallen contact the already bonded
5 abrasive grains, the other abrasive grains are bonded to the already bonded abrasive grains by the deposited metal. In this manner, the abrasive grains are successively bonded onto the core wire. Consequently, the abrasive grains are electrodeposited in an excess amount. In addition, spaces are left among the abrasive grains and pores are fully uniformly dispersed in the
10 electrodeposited abrasive layer (US4547998), which markedly decreases the abrasive retention. By using abrasive having a relatively thin coating layer, only minimum amount of current required for electrodepositing necessary amount of abrasive grains flows to the abrasive grains, so that no excess abrasive grains are electrodeposited
(KR2007/0090074). But, the abrasive retention is compromised.

15 More products formed by using previously coated abrasive grains can be found. For example, US 5250084 teaches a process using magnetic lines of flux to position and orient abrasive particles having a magnetically conductive coating and then bond them by electroplating, but the coating on the abrasive particles is not chemically bonded to the abrasive. US2011/0308371 describes a method to chemically bond metal coated abrasive
20 particles with a low-melting-point metal layer formed by hot-dipping plating or soldering. The metal layer can be laminated with a high-melting-point metal layer formed by electrolytic or non-electrolytic plating to improve wear resistance. US2012/0167482 provides a method to chemically bond metal coated abrasive particles with a soldering film and a plating layer over the soldering film. In all the three patents, the coated particles are not arranged in a regular
25 pattern. On the other hand, coated abrasive grains may be bonded in a predetermined pattern with a plated material, but no metallic bonding can be expected either between the plated matrix material and the non-conductive metal oxide coating (JP2010/076091), or between the plated matrix material and the electrolessly plated coating directly formed on the abrasive surface (US3973925).

30 By chemically bonding coated grains in a predetermined pattern: a) with a molten metal (US4680199, US4916869, US6416560, US7261752, US8377158, US2006/0213128 and US2008/0096479); b) with a solidified organic matrix material (US7258708 and

US7901272) which is less wear resistant, more abrasive tools are formed. In addition, methods are provided (US7866419, US7997358, US7810588, and US8220567) to produce earth-boring bits by sintering/infiltrating a green body formed of a matrix material powder and abrasive grains which are separated each other by the thick encapsulation layer on the
5 encapsulated abrasive grains, by which it is difficult to form a regular position pattern for the abrasive grains. Further, a vitreous bond tool wherein the grains are arranged in a predetermined pattern is reported in US6755720, but no chemical bonding is achieved.

As a result, suitable methods to produce abrasive tools having chemical bonding and precise arrangement of abrasive grains are continually being sought.

10

DISCLOSURE OF INVENTION

The present invention provides abrasive articles comprising a plurality of abrasive grains that are precisely arranged in accordance with a predetermined pattern, and are chemically bonded with a matrix material which at least partially comprises a plated material.

15 The abrasive article can be a tool or a segment of a tool, including a CMP conditioner, a core drill bit for construction or exploration, a wire saw bead, a reciprocating tool, a flexible tool, a profiler and a thin bladed tool used in precise cutting.

The abrasive grains used in the abrasive articles of present invention are selected from the group consisting of natural or synthetic diamond, polycrystalline diamond, cubic boron
20 nitride, polycrystalline cubic boron nitride, fused alumina, sintered alumina, silicon carbide, silicon nitride, and combinations thereof. The grains are previously coated with a coating layer which is chemically bonded to each grain and functions as a bridge to form chemical bonding between grains and matrix. The matrix material includes at least one member
25 selected from the group consisting of an electroplated material, an electroless plated material, a braze, a solder, a sintered material, an infiltrant, an organic material, and a vitrified material. In addition, the matrix can be formed of a series of layers overlying each other, wherein the successive layer has a material that is different than the material of an immediately adjacent layer.

The predetermined pattern of abrasive grains in the article defines at least one member
30 selected from the group consisting of grain position, grain orientation, grain size, and grain protrusion height above the working surface. In one aspect, the grains can be arranged in a uniform pattern (e. g. uniform spacing, uniform grain size, uniform protrusion height, and/or

uniform orientation), and bonded with a matrix material having uniform composition and properties. In another aspect, a non-uniform pattern may be required. In many cases, abrasive articles of the present invention can include at least one reinforced area that wears more slowly than other area(s). The reinforced area, designed to compensate for uneven wear, may
5 have higher concentration of grains, more abrasive type of grains, higher quality of grains, harder matrix, smaller size of grains, lower protrusion height of grains, less apex-oriented and more face-oriented grains towards the workpiece, or combinations thereof.

The present invention also provides a method of making an abrasive article as described above, the method comprising at least the steps of: a) providing a plurality of
10 abrasive grains; b) coating each of the abrasive grains with a coating layer that chemically bonds to each grain; c) arranging the grains on or in the surface of a substrate in accordance with a predetermined pattern; and d) chemically bonding the grains with a matrix material through a bonding process involving plating. The coating step is carried out by a method selected from the group consisting of chemical vapor deposition (CVD), physical vapor
15 deposition (PVD), electroless plating, electroplating, sintering, sputtering, brazing, salt bath deposition, thermal pyrolysis, a sol-gel process, a fluidized bed process, and a combination thereof. The coating layer on the abrasive grains, which may have a layered structure, includes at least one material selected from the group consisting of a metal, an alloy, a metallic composite material, a metal oxide, a metal oxide precursor, and an organometallic
20 coupling agent. Arranging the abrasive grains includes positioning the grains having a specified size at individually specified positions, orienting the grains, and/or controlling the grains protrusion height above the working surface of the final abrasive article. In one aspect, the bonding process for arranged grains can be a plating process such as electroplating and electroless plating. In another aspect, the bonding process can be a multi-step process
25 involving at least one plating step. The plating step involved can be designated to initially bond abrasive grains so that the intended arrangement (e. g. positions/orientation) can be maintained during later step, or be designated to further bond grains that have been initially bonded.

The present invention further provides methods of making an abrasive article
30 comprising a plurality of abrasive grains that are precisely arranged in accordance with a predetermined pattern (including a three dimensional pattern), and are chemically bonded with a matrix material, wherein the methods can include brazing, sintering, or infiltration, by

which it is difficult to accomplish precise arrangement of grains in a conventional manner.

The main feature of the present invention is that by use of previously coated abrasive grains, it provides ways to the desirable combination of chemical bonding and precise arrangement of grains in abrasive products compared to the products where naked grains are randomly placed and/or merely mechanically anchored. As a result, the service life of the expensive abrasive particles can be significantly increased and the cost of making the tools can be minimized by substantially reducing the overall amount of abrasive particles needed in a customized particle pattern while maximizing the efficiency, useful life, and other performance characteristics of the tools compared to a random pattern.

There has thus been outlined, rather broadly, various features of the invention so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying claims and drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows a schematic sectional view of a product, comprising a single layer of abrasive grains bonded with a matrix material;

FIG. 2 shows a schematic sectional view of a cutting tool, having a thickness as thin as the average diameter of abrasive grains involved;

FIG. 3 shows a schematic sectional view of a product, comprising a single layer of abrasive grains bonded to a substrate having a plurality of pits;

FIG. 4 shows a schematic sectional view of a product, comprising a single layer of abrasive grains bonded to protrusions;

FIG. 5 shows a schematic sectional view of a product, comprising three layers of abrasive grains wherein abrasive grains on the working surface are bonded to protrusions;

FIG. 6 shows a schematic sectional view of a product, comprising a single layer of abrasive grains bonded to protrusions that are arranged on the surface of larger protrusions;

FIG. 7 shows a diagram, describing an embodiment for positioning abrasive grains by using a template;

FIG. 8 shows a diagram, describing an embodiment for orienting an abrasive grain by using an orienting hole.

The numbers in the figures have the following meanings:

- 30: An abrasive grain
 32: A coating layer on the surface of an abrasive grain
 40: A matrix
 44: A protrusion
 5 46: A flat surface of a working surface
 47: An interface between abrasive grain layers
 48: A larger protrusion
 49: A groove between protrusions
 50: A positioning aperture
 10 52: A pit
 54: A positioning hole
 56: An orienting hole
 60: A positioning template
 80: A substrate
 15 90: An orienting sheet
 100: A working surface of an abrasive article

Reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the principles of the invention.

20

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1. A single layer of abrasive grains 30 is bonded to a portion of a substrate 80. A matrix 40 is used to chemically bond the grains 30 in accordance with a predetermined pattern, which defines position, grain size, orientation attitude, and/or protrusion height of the grains. The grains 30 are previously coated with an
 25 adhesion-promoting coating layer 32 which acts as a bridge to form a chemical bonding between grains 30 and matrix 40. As used herein, "chemical bond" and "chemical bonding" may be used interchangeably, and refer to a molecular bond that exert an attractive force between atoms at an interface. Chemical bonds involved in the present invention typically
 30 relate to: metallurgical bond between two or more metals; intermetallic bond between a metallic base and electroplated or electrolessly plated material applied to the base; carbides between diamond particles and their metallic coating; nitrides or borides between cubic boron

nitride and its metallic coating; metal oxide between metal and vitreous material; and organometallic coupling agents between metal and organic material. Notably, no chemical bond is expected between nonconductive material, e. g. diamond and CBN, and electrolessly plated coating formed on the nonconductive material with no further treatment to enhance the
5 adhesion.

FIG. 2 shows a product having a single layer of grains 30 chemically bonded with a matrix 40 in accordance with a predetermined pattern. One of the cross sections of the layer acts as the working surface 100 of the product which is particularly suitable for cutting. The substrate on which the product is formed has been removed. The thickness of the product can
10 be as thin as the average diameter of grains involved, generally (0.05-0.70 mm), or even thinner if thicker metallic coating and/or group placement are accepted for small particles. Actually thin-bladed tools such as narrow band saw, reciprocating saws, wire saws, circular saws, thin-walled core drill bit, are urgently desired in precision cut of expensive materials, such as monocrystalline or polycrystalline silicon, germanium, gallium arsenide, quartz,
15 aluminum oxide, beryllium oxide, sapphire, glass, electronic crystals, optical or magnetic discs. FIG. 3 shows a single layer of grains 30 chemically bonded with a matrix 40. The layer is bonded to a substrate 80 which has a plurality of pits 52 (blind holes) in accordance with the predetermined position and grain size pattern of the grains, wherein one grain seats in each pit. In this manner, the layer of grains can be bonded more strongly to the substrate.

20 Notably, a plurality of grain layers can be superimposed to form a three dimensional structure (i. e. multi-layer). By arranging the grains of each layer, arrangement of the grains can be controlled in each dimension. Of course, each layer needs not have the same concentration and size, nor needs the thickness and matrix material be the same in each layer. For example, two abrasive layers can be laminated with an inner layer having less abrasive
25 grains, less grain concentration, and/or softer matrix material to form a desired wear profile on the cutting/grinding surface during use. In addition, layer(s) of grains can also be applied to the other side of a substrate to form a double-sided product where the substrate becomes a hub, and one of the cross sections of the layers acts as the working surface, which is particularly suitable for cutting.

30 Furthermore, working surface of an abrasive article may have geometric protrusions arranged in accordance with a predetermined pattern, and each of the protrusions is sufficient in size enough to accommodate at least one grain. The protrusions may have a flat and even

upper surface. The concave portions between protrusions provide paths for swarf to leave the cutting zone and conduct coolant to and from the work piece. The protrusions on a working surface may result from protrusions of the substrate on which the abrasive article is formed, or from removal of the substrate having corresponding concave portions. FIG. 4 shows the working surface 100 of an abrasive article having a single layer of grains 30 chemically bonded to protrusions 44, rather than to the flat surface 46 of the working surface 100, ensuring great protrusion height of the grains 30 above the working surface. To protect the flat surface 46, abrasive particles same or not as the grains 30 can be disposed on the flat surface 46. FIG. 5 shows the working surface 100 of an abrasive article having three layers 11, 12, 13 of grains 30 chemically bonded with a matrix 40 in accordance with a predetermined three dimensional pattern. The grains 30 on the working surface 100 are bonded to protrusions 44, rather than to the flat surface 46. The bonding strength of the interface 47 between layers (e. g. 11 and 12) can be enhanced by the pits 52 formed in the surface of a former layer (e. g. 11) before imposing a new layer (e. g. 12). Layer 11 is the first formed. When used, grains 30 of layer 11 first wear out and fall off, and the matrix of layer 11 remaining on the surface of layer 12 becomes thin easily and tends to fall as well since the relatively weak bond of the interface 47. As a result, inner protrusions of layer 12 are exposed and sharpness continues. FIG. 6 shows the working surface of a product comprising a plurality of grains 30 bonded to protrusions 44, which are accommodated on the surface of larger protrusions 48. Each of the larger protrusions 48 has a substantially flat upper surface sufficient enough in size to contain at least one smaller protrusion 44. These larger protrusions 48 are arranged in accordance with a predetermined pattern and are separated by grooves 49 having U or V cross sectional shapes. Obviously, the product in FIG. 6 has great grain protrusion height and excellent cutting ability which is urgently desired for cutting tools (circular saw, band saw, gang saw, frame saw), core drill bits for construction or exploration, grinding wheel, and wire saw beads in mining industry.

The grains in an abrasive article of the present invention can be arranged at individually specified positions in accordance with a predetermined position pattern. In a multi-layer product, the predetermined pattern is a three dimensional pattern. The grains having may also be arranged in accordance with a predetermined grain size pattern. They can also be oriented in accordance with a predetermined orientation pattern. For example, the grains 30 (as shown in FIG. 4) on the working surface 100 of the product may be arranged in

a direction with a sharp point extending away from of the working surface 100. Typically, the grains can be orientated in three attitudes, respectively exposing an apex, an edge, or a face of the grain towards a workpiece. In addition, the grains may also be arranged in accordance with a predetermined pattern of protrusion height above the working surface (e. g. a uniform height or series of heights that are along a designated profile having a slope, multiple slopes, a dome shape or other curved shapes). In one aspect, the grains can be arranged in a uniform pattern (e. g. uniform spacing, uniform grain size, uniform protrusion height, and/or uniform orientation), and are bonded with a matrix material having uniform composition and properties. A substantially uniform pattern can help distribute substantially equal work load to each particle. Additionally, a uniform protrusion height ensures a smooth finish of the work piece surface. In another aspect, a non-uniform pattern may be required. For example, the grains may be arranged in controlled, random spatial arrays, i.e., the distance between the center-point of adjacent grains may vary from grain to grain within a minimum value to avoid any grain-to-grain surface contact, and a maximum value. By employing non-uniform distances (e. g. in a CMP pad conditioner), vibration periodicity may be avoided since a uniform grid gives rise to a periodicity in vibration arising from the tool movement that, in turn, can cause waviness or periodic grooves on the workpiece or uneven wear of the abrasive tool or of the workpiece.

In many cases, abrasive articles of the present invention can include at least one reinforced area that wears more slowly than other area(s). The reinforced area may have higher concentration of grains, more abrasive type of grains, higher quality of grains, harder matrix, smaller size of grains, lower protrusion height of grains, less apex-oriented and more face-oriented grains towards the workpiece, or combinations thereof. The reinforced area can be designed to compensate for uneven wear. For example, circular saw blades tend to wear faster on the both sides than the center. And the cross section of the saw may become convex in shape with the center bulging above both sides. This configuration typically slows the cutting rate of the saw blade. Moreover, the protruding profile may also cause the saw blade to deflect sideways in the cut slot. Thus, the two sides of the saw need to be reinforced. Even more preferably, the central abrasive layer can be designated to be greatly worn away so that an annular depression is formed in the center of the cross section and cuttings generated by cutting are taken in to the annular depression side and removed by the rotation of the cutting blade, thereby preventing the generation of burrs. Similar annular depressions between layers

in a multiple layered cutting tool are also desired. Other exemplary areas needed to be reinforced include: the leading edge of each tooth in a segmented saw which is much more susceptible to wear, the perimeter of a disc-shaped grinding tool which generally spins faster than the center of the disc-shaped tool, the leading edge of the disc on which there is more pressure, and the free end of a honing tool which is in abrading contact with the workpiece surface to a greater extent.

Referring now to the matrix 40 used to bond the grains. The matrix 40 includes a plated material, such as nickel, cobalt, copper, iron, and their alloys, and combinations thereof, wherein the plated material is formed by a plating method including electroplating and electroless plating. In addition to plated material, the matrix can further include material made by a process rather than plating, such as soldering, brazing, welding, spraying, hot-dipping, sol-gel, electrophoretic deposition, sintering, curing, vitrifying, and infiltration. The non-plated material can be a pure metal such as copper, cobalt, iron, nickel, chromium, titanium, zirconium, tungsten, tin, silver, manganese, zinc or mixtures thereof, and a metal alloy such as copper-nickel, copper-manganese, brass, bronze, nickel-cobalt, nickel-iron, nickel-phosphorus, nickel-manganese, nickel-tungsten, nickel-cobalt-manganese, and a commercially available alloy known by the trade name MICROBRAZ LM (7 wt % chromium, 3.1 wt % boron, 4.5 wt % silicon, 3.0 wt % iron, a maximum of 0.06 wt % carbon, and balance nickel), made by Wall Colmonoy Company (USA). Any low-melting point metal (e. g. a solder/braze) may also be included. Vitrified bond materials comprising silica, boron oxide, sodium oxide, aluminum oxide and alkali and alkaline earth metals may also be included. Vitreous material is hard, chemically resistant, scratch resistant. Silica-alumina glass is commonly used. Organic materials can be included in the matrix as well, such as a thermosetting material including phenol formaldehyde, acrylic based resin, amino based resins, and epoxy resin, as well as a thermoplastic material including acrylic, polyurethane, polyurethane acrylate, phenol, polyimide, and other materials used in the art. Organometallic coupling agent can be added to improve adhesion between organic matrix and metal coating on grains.

The matrix material may be discontinuous, for example in a flexible product wherein the grains are bonded to discrete material to ensure the flexibility. The matrix can be formed of a series of layers overlying each other. For example, one successive layer can have a composition that is different than the composition of an immediately adjacent layer. The

matrix can comprise an inner harder layer and an outer softer layer (e. g., nickel/copper, metal/organic, metallic composite/pure metal), wherein the embedment of the harder layer provides a hinge point for the grain while most of the grain is held in the softer binding layer, thus, a `brush` effect can be obtained, leading to a more gentle cutting. In addition, an outer
5 vitreous layer can provide chemical and mechanical protections for an inner metallic layer. The matrix, particularly in a multiple layered product can contain a plurality of pores to facilitate the chipping and breaking of material from the workpiece, and the passing and holding a liquid coolant, since the grains are chemically bonded and a reduced amount of mechanical support for each particle is acceptable. Such pores may be implemented in a
10 variety of manners. For example, air may be bubbled through a powdered matrix material during the consolidation thereof, particles that disintegrate during the heating step may be used, or the pores may result simply from the consolidation processing procedure, such as sintering. Further, the pores may result from addition to bond components of hollow ceramic spheres, e. g. silica, mullite and alumina.

15 Optionally, the matrix can include a filler material suitable for enhancing performance properties of the abrasive article. The filler may be in a form of powder, whisker, nanotube, fiber, porous sheet, woven, knitted or embroidered fabric (e. g. a mesh) made of fibers, and combinations thereof. The porous sheet may be a perforated sheet having through-holes or a sheet having pits (blind holes). The filler may be coated with one or more additional
20 material(s), to help retain the filler, for example. The concentration of fillers may be uniform or may vary as desired, to compensate uneven wear in the tool, for example. In one aspect, the filler can be a ceramic powder known to one skilled in the art, including alumina, silica, zirconia, silicon carbide, silicon nitride, titanium carbide, diamond, tungsten carbide including sintered tungsten carbide granules, cubic boron nitride, boron carbide, carbon, or mixtures
25 thereof. Particularly preferred filler materials are those in the form of nano-scale particles. Alternatively, the filler can be solid lubricants, such as graphite, molybdenum sulfide, polytetrafluoroethylene, hexagonal boron nitride. In another aspect, the filler can be fibers or fabric made of fibers, including carbon fibers, boron fibers, graphite fibers, metal fibers (e.g., stainless steel, tungsten, iron, molybdenum, cobalt, or combinations thereof), glass fibers,
30 polymeric fibers (e.g., Kevlar), ceramic fibers (e.g., silicon carbide, tungsten carbide, alumina or silica).

Referring now to the grains 30. Any abrasive suitable to grind a particular workpiece

may be used. It may be a conventional abrasive, a super abrasive, or a combination thereof. Examples of conventional abrasives include aluminum oxide, silicon carbide, mullite, silicon dioxide, zirconia, wurtzite boron nitride, cerium oxide, titanium carbide, tungsten carbide, boron carbide, titanium diboride, silicon nitride, and combinations thereof. Examples of super
5 abrasives include cubic boron nitride (CBN), hexagonal boron nitride, boron suboxide, diamond (natural and/or synthetic), and combinations thereof. The boron nitride and diamond may be polycrystalline or monocrystalline, including crushed polycrystalline diamond (PCD) and thermally stable polycrystalline diamond (TSP). The abrasive grains can also be a composite material (e. g. agglomerate) comprising a plurality of fine grains.

10 The chemical bonding of abrasive grains 30 with the matrix 40 is accomplished by the adhesion-promoting coating 32 chemically bonded to the grains 30. The coating 32 serves as a bridge to form a chemical bonding between grains 30 and matrix 40, e. g. grains having metallic coating can get chemical bonding with a metallic matrix material formed through a plating (e. g. electroplating and electroless plating) or fusing (e. g. brazing and sintering)
15 process; grains having a metallic oxide precursor coating with a vitreous matrix, and grains having an inner metallic coating and an outer coating of organometallic coupling agent with a resinous matrix. Notably, similar bridge for chemical bonding can be formed between layered matrix, e. g. metallic layer and resinous layer through a coupling agent, metallic layer and vitreous layer through a metallic oxide.

20 The chemically bonded coating on the grains can be made by a number of methods known in the art including, for example, chemical vapor deposition (CVD), low pressure chemical vapor deposition (LPCVD), sputtering chemical vapor deposition, low temperature CVD, plasma assisted chemical vapor deposition, physical vapor deposition (PVD), PVD sputtering, metal vapor deposition (MVD), sintering, sputtering, brazing, chemical reduction,
25 gaseous vapor deposition, electroless plating, electroplating, salt bath deposition, thermal pyrolysis, sol-gel process followed by a reaction heat treatment, a fluidized bed process followed by a sintering process, or any other metal coating means, or a combination thereof. Several products having an adhesion promoting coating are commercially available. For instance, diamond grains having an adhesion promoting coating comprising chromium under
30 the trade designation "MBS-960CR2", or comprising titanium under the trade designation "MBS-960TI2" are commercially available from General Electric Co. (Worthington Ohio.).

The coating layer chemically bonded to the grains is generally formed from a reactive

element capable of forming (singly or in combination) carbides, nitrides, borides, carbonitride, or boronitride to the surface of the abrasive material. Particular reactive elements may bond more favorably with particular abrasives. Examples of carbide-former for diamond are tungsten, titanium, tantalum, zirconium, molybdenum, hafnium, chromium, vanadium, silicon, 5 aluminum, boron, lithium, magnesium, manganese, and niobium. Chromium is the most preferred since it bonds strongly with diamond. Examples of nitride former for CBN include Al, B, Cr, Li, Mg, Mo, Mn, Nb, Si, Ta, Ti, V, W, Zr and combinations thereof. Titanium, chromium and zirconium are preferred. The coating layer may also be a metal alloy. For example, diamond can be coated with a Ti-Cr alloy composed of an inner carbide layer 10 enriched in Cr content and an outer layer depleted in Cr content. Alternately, a tungsten and titanium alloy layer may be deposited directly on diamond by a known method, e.g., by CVD. The tungsten controls and reduces the activity of the titanium while the titanium provides a good bond to the diamond. The alloy layer can comprise a base metal of copper, cobalt, nickel or iron and a combination thereof, and at least one carbide/nitride former. The alloy coating 15 chemically bonded to the grains can be formed by heating a mechanical coating layer having the alloy composition, assisting in the formation of carbide/nitride on the grains surface. The mechanical coating can be formed by electroless plating, electroplating, or by coating of a mixture of metallic powders and a temporary organic binder.

The coating on grains can have a layered structure. For example, an oxidation resistant 20 coating (e. g. W, Ta, Mo) can be applied to an inner layer (e. g. Cr) on diamond. Optionally, an intermediate layer containing titanium, vanadium, zirconium, niobium, tantalum, iron, cobalt, nickel or copper, can be introduced to protect the inner chromium layer against attack by halide containing gas during the CVD deposition of the outer layer of tungsten, or molybdenum. Similarly, an oxidation resistant layer (e. g. Ta) can be applied to an inner layer 25 (e. g. titanium and zirconium) of CBN. To enhance the bonding strength between layers, heat treatment is an option.

The coating on the grains can also be a composite material containing small hard particulates, such as diamond, cubic boron nitride (CBN), tungsten carbide, titanium carbide, boron carbide, silicon carbide, silicon nitride, zirconium oxide, aluminum oxide, titanium 30 boride, tantalum carbide, or mixtures thereof. The use of finer particles surrounding a larger particle may allow a larger depth of cut and sharper cutting elements due to controlled exposure of fresh abrasive. The composite coating can have a layered structure with

concentration of at least one of the alloying components and hard materials varying from one layer to another. For example, the inner layer is hardest or most abrasion resistant while succeeding layers are generally softer. Such coatings may further increase the retention of the grain. In a variation, concentrations in the coating do not change suddenly so that the weak
5 interface created by a sharper transition between two materials is eliminated.

Matrix materials may not wet and thus not bond well with the coating layer on the grains therefore, an outer wetting layer may be added to the coating layer on the grains. The selection of wetting layer materials may thus depend on the compositions of the coating layer and the matrix materials. For use in a typical metallic matrix, preferred wetting layer material
10 includes nickel, cobalt, copper, and iron, or alloys of these metals. In case of a resinous matrix, the wetting layer can be an organometallic coupling agent including titanate, zirconate, silane, aluminum coupling agents or thiolate based compounds or mixture thereof. In case of a vitreous matrix, the wetting layer can be a metal oxide or oxide precursor such as nitrides, carbides, boride, oxynitrides, oxycarbides, carbonitrides or elemental precursor materials.
15 Preferred metals are titanium, nickel, copper, silver, cobalt, molybdenum, and alloys thereof. Titanium dioxide is the most preferred. However, zirconia, alumina, silica or other material which dissolves slowly in alkali glasses can be used. It is possible to provide the metal oxide coating in a number of ways, for example, by applying the metal oxide directly to the grains (e. g. sol-gel technique) or by conversion of elemental metal or other metal oxide precursor
20 during manufacture of the abrasive tool. Notably, a layer of a reactive glass or ceramic which is reactive with CBN, preferably forming a boron oxide or silicate may be coated on CBN. Examples of reactive layer are borate glasses, such as Pyrex or Pyrex-like materials.

To further increase grains retention in the matrix, the coating on the grains may include a rough surface which allows for increased surface contacts as well as a mechanical
25 interlock. The rough surface may have protrusions, irregularities or imperfections arranged in various shapes such as chiral, spire-like, helical, spherical, and needle-like.

Referring now to the substrate 80. Typically, the substrate has an exposed surface to which the grains are to be arranged. The substrate may provide a permanent support for an abrasive article, or a temporary support for fabrication of a stand-free article, or a carrier of
30 the abrasive grains for fabrication of an article, or a transfer for arranging grains onto/into a second substrate to which the grains will be bonded. The substrate may be metallic or non-metallic, substantially flat or contoured, concave or convex, planar or non-planar, flexible

or rigid. It can also have multiple faces. The geometric shape can be disk, rim, ring, cylinder and conical shapes, and combinations thereof. The substrate may also be supported by a support member such as plastic, fiberglass, metal, wood, rubber or the like. The substrate may be flexible if the abrasive article is to have flexible properties, such as abrasive belts. A
5 flexible abrasive tool is highly desirable for polishing non-flat pieces, or for fixing to a contoured shaping device such as a router. These flexible tools have been found to engage in freer cutting and fine, precision grinding operations.

The substrate surface may have some concave portions which are sunken under the surface. For example, it may include an elongated groove having a cross-section such as a
10 semi-circle, a semi-oval, a U-shape, a V-shape, or a rectangular shape; a pit (a blind hole) such as a semi-sphere, a semi-ellipsoid, an inverse cone, a rectangular pole, a cylinder, a truncated cone or pyramid, a bowl or the like; a space between projected portions; and furthermore a through hole passing through the opposing side and having various shape of cross-sections (e. g. a perforated sheet). The concave portions having various shapes can be
15 combined with each other for various purposes. FIG.3 shows some pits 52 designed to enhance the bonding strength between matrix 40 and substrate 80. Pits in a substrate can also lead to the great protrusion of grains (FIG. 4 and FIG. 5) since the pits will translate into the protrusions after removal of the substrate from the resultant bonding layer. The pits can also be designed to position/orient the grains as described later.

In addition, groove (e. g. having U or V cross-sectional shapes) between geometrical
20 protrusions may provide paths for swarf to leave the cutting zone and conduct coolant to and from the work piece. The grooves may all have same width and/or depth, or alternatively a groove having a greater width and/or depth can be formed at an interval of a certain number of grooves on the crossed-strip pattern as a region dividing groove. The protrusions formed on
25 at least one side of a substrate may have a rectangular or cylindrical shape and a flat and even upper surface which is sufficient enough in size to accommodate at least one abrasive grain. Further, the upper surfaces of the geometrical protrusions can have a plurality of smaller geometrical protrusions formed by a pair of diagonally-crossed or a number of crossed-strips of grooves having U or V cross-sectional shapes. The presence of the smaller protrusions
30 accommodating at least one grain will more effectively drain the residues.

All of these concave portions can be formed through various methods including mechanical processing such as digging, cutting, scoring, grinding, machining, stamping,

rolling, knurling, compressing, drilling, laser assisted machining, water jet cutting, ion beam milling, and shot peening, etc. They may also be formed by chemical and/or electrolytical etching, e. g. using well know photochemical etching techniques, such as those used in semiconductor processing. Alternatively, the concave portions can be formed by a molding
5 process. A multi-step process may be required.

The substrate may include at least one platable surface to facilitate deposition of metal ions during a plating process. The platable substrate can be made of any conductive material including iron, aluminum, tin, lead, copper, carbon, graphite, their alloys (e.g. steel, stainless steel, bronze, and brass), composites, and metal filled plastic. Alternatively, the platable
10 substrate can be a surface metalized material, e. g. a resinous sheet, in particular made by various molding methods. The metallization can be accomplished by attaching a metal foil, depositing a metal film through electroless plating, vapor deposition, painting, spraying (e. g. arc spraying and plasma spraying), sputtering, and electroplating, or by coating an electrically conductive adhesive (e. g. a conductive resin adhesive of THREEBOND 3300 series), or an
15 insulating adhesive containing conductive powder (e.g., silver powder). Flexible platable substrate may be a fiber /resin (e. g. epoxy, polyester phenolic resin, phenol formaldehyde resin) laminate such as that supplied by Westinghouse and GE, which is used for printed circuit board applications, or a copper clad, fiber free resin system such as that supplied under the trademark Kapton (by DuPont), which is used for flexible printed circuits. The flexible
20 substrate may include perforated or expanded metallic sheets, metallic mesh having flattened portions at the intersections of the wraps and woofs, or woven or non-woven fabric (e. g. a mesh) comprising conductive fibers (e. g. W, stainless steel, boron, carbon, graphite), or insulating fibers (polymer, glass or ceramic) at least partially coated with a conductive material. The platable fabric can also be made of nonconductive fibers interlacked with
25 conductive fibers.

Electrically insulating fabric, including woven and non-woven fabrics of cotton, nylon, polyester, wool, silk, rayon, Terylene, Kevlar, silica, glass, and ceramic (e. g. BN, SiC, B4C, Al2O3), can also be used if measures are taken to allow metal to deposit thereon (to be described later). A particularly suitable fabric is made of polyamid yarn, such as p-poly
30 (phenylene) terephthalamide yarn, which is supplied under the trademark Kevlar. Preferred insulating fabrics comprise screen printing cloths, particularly monofilament polyester one-over-one weave screen printing cloths. Although flexible substrate is usually in the form

of woven fabric (e.g. a mesh), a nonwoven fabric can be used for fine grinding operations, since the randomly arranged fabric is very difficult to tear into pieces. For heavy duty dry-grinding operations, two or even more fabric layers, preferably including at least one non-woven layer, can be stacked together without special attention to their mutual positioning
5 or orientation. To prevent degradation of fabric due to fraying and scuffing during heavy industrial use without impairing the flexibility, the fabric can be coated with a copolyester elastomeric resin.

To define the shape of the resultant product, the platable substrate can be partially covered with an insulating material. For making a flexible abrasive article having discrete
10 deposits, an insulating mask having a plurality of openings can be applied to the substrate surface. The no plating area resulting from the insulating coverage can also lead to the fabrication of gaps, slits or pores in serrated, segmented or porous tools to allow water to be delivered to the cutting face. Sometimes, the no plating areas can be designed to decrease the amount of materials to be cut. In addition, use of insulating material can provide a way to
15 mass production of abrasive tools or segments for tools, which are formed on the same substrate, but separated by an insulating material. The insulating material can be formed of a rubber material or a resin material such as acrylic resins, alkyd resins, epoxy resins, phenoxy resins, phenolic/latex resins, or mixtures thereof.

Once a substrate is provided, grains can be arranged on or in the substrate surface.
20 Prior to arranging grains, the substrate surface may be prepared by grinding and/or finishing through mechanical and/or chemical or electrolytical processing, or sometimes by sand-blasting with abrasive material to depolish the glossy surface to achieve mechanical interlocking by creating microscopic cavities. Alternatively, adhesion can be enhanced by applying a thin layer, e. g. through electroplating, to the substrate to avoid direct contact of
25 grains with the substrate. But in some cases, the substrate may be treated (e. g. passivated) to prevent a strong adhesion, and facilitate subsequent removal of the grain layer from the substrate. Use of a chemically soluble substrate or a soft deformable substrate may also help the removal. In addition, prior to arranging the grains, an anti-static material can be coated over the grains to prevent them from sticking together through static forces. Alternatively, the
30 grains can be uniformly scattered by an automatic vibration feeder, which uses vibrational forces to help counteract electrostatic attractions between grains. A vibration feeder can use a variety of a vibrational sieve meshes which can also control the size of the grains to be

scattered. More than one layer of sieves can be used.

Arranging the grains on/in a substrate in accordance with a predetermined pattern can include positioning the grains having a specified size at individually specified positions, orienting the grains, and/or controlling the grains protrusion height above the working
5 surface of the final abrasive article. The arrangement may be accomplished by a variety of methods, all of which would be considered to be within the scope of the present invention. For example, positioning grains can be accomplished by using a template having a plurality of apertures corresponding to the predetermined position and grain size pattern of the grains. One side of the template is positioned against the surface of a substrate, and grains can be
10 spread over the other side. The grains in the apertures can contact the substrate surface so that they can be secured thereto. The remaining unsecured grains can then be removed. Uncut regions of the template may correspond to open channels on the resultant tool between abrasive parcels. The template can be laminated with a substrate (e. g. a fabric), for example, by adhesive or by heat and press.

15 The template apertures could be designed to have a diameter in the range of 1-2 times average particle sizes so that only one grain will fit in each. Alternatively, the diameter of the apertures may be 1.75 to 2.5 times of the diameter of the grains to accommodate a group of grains having an average number of 2 to 8. For smaller particles, say, less than 100 micrometers in diameter, thicker coat on the grains and/or group placement may be helpful for
20 the convenience of making the apertures. Optionally, multiple size apertures can be designated to accommodate differing size grains in the same tool in which case the larger grains would be applied first followed by the smaller grains. Generally, the thickness of the template ranges from 0 to 2 times the average diameter of grains to ensure that only a single layer of grains is located in apertures and grains superimposed upon the grains located in
25 apertures could be easily moved away from the apertures. When pits 52 are formed in a substrate 80 corresponding to the apertures 50, as shown in FIG. 7, the height from bottom of the pits 52 to the upper surface of the template 60 may range from 0 to 2 times the average diameter of grains 30.

30 The template may remain in place until the located grains are permanently bonded, or may be removed after the grains are temporarily affixed. In order to remove the template easily, the template may be temporarily attached to the substrate by a magnetic force, or with an adhesive which could be mechanically stripped or chemically dissolved. Alternatively, the

template material is chemically soluble (e. g., water soluble), or burnable. The template material can be organic, ceramic or metallic, such as a masking tape, a silk screening material, a painted material, a stainless steel sheet, and a disposable material such as plastic film and fiberboard sheet. The template may be electrically and/or magnetically conductive, or at least one surface of the template is electrically conductive. Alternatively, the template may be a conductive sheet covered with an insulating material. The template can be flexible which permits it to conform to a curved surface and to be rolled up for storage or for deployment in an endless belt configuration.

The template apertures could be formed before or after the template is in place, in various ways including mechanical and/or chemical or electrochemical mechanisms, such as stamping, molding, digging, cutting, rolling, knurling, compressing, drilling, cutting by laser or electron beam, chemical etching, electrolytical etching, photoetching, screen printing, and combinations thereof. For example, the template can be applied to a substrate surface by coating with a layer of a photopolymer and exposing the photopolymer to a radiation (e. g. ultra violet light) through a negative having images correspondent to an aperture pattern. The coating is then developed, preferably by treatment with an alkali, such as sodium hydroxide. The photopolymer can be a dry film photopolymer, such as a dry film photopolymer supplied under the name Riston by Dupont, or a liquid film resist supplied by Kodak, GAF, Dynachem, Dupont, or Fuji film. Alternatively, the template may be applied by silk screening, in which case the template may be made of resin based or oil based ink. The printing method is inexpensive and easy to operate. However, the employment for a finer grain size (e. g. less than #120) is not recommendable, since the print becomes often loose and a pattern is apt to be unclear.

Additionally, openings-including blind holes (e. g. pits/indentations) and through holes (e. g. perforations)-in a substrate corresponding to the position and grain size patterns of grains can be used to position grains in the similar manner as the template apertures do. Abrasive grains positioned in the openings can get affixed by deforming the openings of the substrate. The positioning of the grains may also be carried out by drawing a vacuum (suction) through a rigid plate having a plurality of perforations which are arranged to correspond with the desired grains pattern. The size of each perforation (e. g. 3/4 of the particle size) is such that when the plate is brought near a source of the grains, the vacuum draws the grains against the plate, and only one grain is held over each perforation. Once the grains are securely held

by the vacuum, the plate is positioned over the substrate surface, and then the vacuum level is adjusted so that the grains drop onto the adhesive coated substrate surface. One alternate of the plate perforation is hollow cylinders such as tubes or needles, with the cylinder ends arranged in a predetermined pattern. Similarly, a robotic arm may be used to pick an array of
5 grains, with a single grain held at each point of the array.

Positioning the grains in a predetermined pattern may also be carried out by placing an array of adhesive droplets on the substrate surface and then centering an abrasive grain on each droplet. The droplets can be sized, e.g. 30-70 the average size of the abrasive grains, to accommodate no more than a single grain on each adhesive droplet. This method is
10 advantageously suitable for arranging small particles (e.g., less than 90 microns in size). The adhesive droplets may be formed by a screen printing method, a micro-dosing system such as Microdrop.RTM available from Microdrop GmbH, Norderstedt, Germany, or a jet printer with the jetting cartridge containing an adhesive. The jetting adhesive can be a two part adhesive (i. e. a resin and an accelerator or an activating agent) which are jetted from different
15 nozzles. An array of needles or needle type members may be configured for depositing an array of adhesive droplets to a substrate. Generally, the needles are hollow and can contain an adhesive material within the needles. Alternatively, the array of needles need not be hollow, but may be dipped into an adhesive source. The adhesive can adhere to the needles until the adhesive is dabbed or stamped onto the surface of the substrate. The adhesive source can
20 resemble a sponge or pad that is capable of retaining fluids, similar to an ink pad.

The adhesive droplets can also be transferred from a transfer to which the droplets are initially placed. Further the adhesive droplets can be formed by spraying or pouring after the substrate is masked by a stencil having openings. Alternatively, the droplets may be formed by first applying an adhesive coating to the entire surface of the substrate and then followed
25 by one method among: a) covering the surface with a masking tape having holes. The masking tape may be removed by mechanically peeling or chemically dissolving, if necessary, once the grains are secured; b) removing adhesive on the upper surface of the coated substrate which has an array of indentations/pits, leaving adhesive droplets on the surface of indentations/pits; c) removing unwanted portions of the coating by moving a tool containing
30 flattened tip members (like a flat head screwdriver) twice, perpendicular to each other, leaving an equally-spaced, predetermined grid pattern in accordance with the tip width and the distance between the tip members; d) removing unwanted adhesive by laser or electron beam.

Orienting grains can be accomplished by various methods, for example, by a magnetic force which will orient the grains according to their crystallographic structure, or by pits or indentations in the substrate, having a shape of a pyramid or a cone (truncated or not) with an opening angle (e. g. 90-12 degree). An abrasive grain may fully seat in a pit having a 120
5 degree opening angle, and may not fully seat in a pit which has an opening angle of 90 degree, due to the steepness of this angle. The width of the pits should be large enough to allow the grain to come to rest along one or both sides of the pit, or in direct contact with the periphery of the pit. If the bottom of the pit is flat, the width at the bottom should not be great enough to allow a flat face of the grain to come to rest at the bottom of the pits.

10 Preferably, orienting a grain can be accomplished by an orienting hole configured to selectively hold one of the apex, edge, or face of a grain. Orienting holes can be formed of a micro sieve, such as nylon. In practice, the orienting hole can be attached to, or be formed integrally at one end of a positioning hole and/or a positioning aperture in a template. FIG. 8 shows an example of such an orienting hole 56 of an orienting sheet 90, which is smaller than
15 the average apex size of the grain 30. The grain 30, positioned by a positioning hole 54 of a substrate 80, is forced to be suspended at the upper edge of the orienting hole 56, with the sharp portion of the grain 30 directing downward. To facilitate orientation, the diameter of the positioning hole 54 continuously increases, like a bowl, for example. A magnetic force and/or a vibrational force meaning to oscillate back and forth, up and down, or from side to side,
20 intermittently or continuously in a rapid movement, may also be useful. Alternatively, grains may be picked up and positioned with a surface containing numerous flared holes providing suction. The holes can be configured to orient the grains into selected attitudes through a mechanical matching process. A gas flow through the gap between the abrasive grain and the hole may assist in the orientation of the grains.

25 Properly arranged grains may be temporarily affixed so that the arrangement (e. g. position/orientation) can be maintained. The affixing can be accomplished by an adhesive, a force of magnetism, electrostatic, friction, gravity, and the like, or by a combination thereof. For example, they can be affixed by an adhesive coated on the substrate prior to placing the positioning template. The adhesive can be a water-based adhesive. The adhesive may contain
30 conductive powders such as silver or copper to facilitate electrodeposition, or may contain fusible powders of metal, resin, glass, or ceramic so that the grains will be bonded through subsequent firing. In addition, the arranged grains may be affixed by pressing them into the

substrate. This pressing method is preferably suitable for affixing grains in templated positions to a soft surface, e. g., a fusible sheet, a pliable sheet comprising fusible powders of metal, resin, glass, or ceramic, or a mesh-like or perforated sheet. Specifically, a template having a thickness preferably $1/3$ to $2/3$ of the average height of the grains is laid on the top of a soft sheet, and a layer of grains is then spread over the template so that each aperture receives a grain. Those particles not falling into the apertures in the template are removed. A press (e. g. a steel plate) is laid over the particles, which rest in the apertures. The grains are pressed at least partially into the sheet. After removing the template, the press may be used again to press the grains firmly into the sheet, if necessary. Similarly, grains arranged on a porous substrate (e. g. a mesh) can get affixed by being pressed into the openings of the substrate. Though the press typically is a strong, rigid material, softer materials may provide a benefit. For example, a press constructed from a hard rubber, may conform slightly to the shape of the grains, and thus more effectively push smaller as well as larger grains through the soft sheet to a rigid support to which the soft sheet is attached.

Arranging grains on/in a substrate can also be accomplished by transferring grains to the substrate. The grains are initially arranged on/in the surface of a transfer and temporarily affixed to the transfer, by adhesive (continuous or discontinuous), for example. Above-recited methods for arranging and affixing grains to a substrate can be followed. The transfer can be a flat plate or roll, or a deformable sheet. The transfer can be configured to orient grains, for example, by forming orienting pits/ holes in the transfer surface, e. g. a woven fabric or a perforated sheet. The transfer can be made of a metal, a ceramic, a plastic, and combinations thereof. Transparent plastic is preferred such that the transfer of grains can be easily monitored. A flexible transfer may be required for storage convenience or for a curved or more complex shaped substrate. A magnetic force can help grains to get contact with the substrate surface when transferring coated grains to a substrate. The transfer may be removed once the transferred grains get affixed to the substrate. The affixing of grains to the substrate can be accomplished by an adhesive, a force of magnetism, electrostatic, friction, gravity, and the like, or by a combination thereof. For examples, the grains can get affixed by being pressed into the substrate; or by an adhesive more strongly adhesive than the adhesive on the transfer. The removal of the transfer may be conducted by a mechanical mean (e. g. peeling), or by a chemical mean when the transfer material or the adhesive on the transfer is chemically soluble (e.g., water soluble). Notably, insulating adhesive (e. g. discontinuous adhesive

droplets) used to affix grains to the transfer can be designated to remain on the tips of grains after removal of the transfer, providing an effective mean to prevent metal deposition on the tips of the grains during subsequent plating. Similar prevention of metal deposition can be accomplished by the use of a porous insulating transfer (e. g. a mesh, a woven fabric, or a perforated sheet/tape). The pores allow passage of metal ions therethrough and deposition of metal onto the substrate while the transfer remains on the substrate. Alternatively, the insulating transfer can be a continuous material without pores if the substrate has pores to provide such passage.

Arranging grains can also include controlling protrusion height of the grains above the working surface of the final product. A uniform height or series of heights that are along a designated profile can be accomplished by a number of methods, for example, by pressing the grains arranged on a substrate with a rigid plate or a contoured or otherwise shaped surface, or by transferring grains affixed to a transfer having a flat, or a contoured or otherwise shaped surface. The transfer surface has a shape that is inverse to a vertical pattern to be imparted to the abrasive particles. As such, the shape of the transfer surface can be adapted to suit many applications for abrasive tools. For example, the transfer surface can be substantially flat, concave, or convex, or it can include both convex and concave portions. In another example, which can be particularly useful for chemical mechanical polishing (CMP) applications, the concave shape of the transfer surface can have a slope of about 1/1000, or concavity of about 1/1000.

Once the grains are arranged in accordance with a predetermined pattern, and temporarily affixed if it is, the grains can get chemically bonded with a matrix material through a bonding process which involves plating technique. In one aspect, the bonding process can be an essentially pure plating process (not involving a non-plating bonding process), if the grains are arranged to a platable substrate, loose or temporarily affixed. There are several plating methods, and many variations, such as electroplating, electroless plating, electroforming, jet electroplating, brush electroplating, and the like. Fillers can be introduced, if necessary, into the matrix material by adding them to the plating solution. Since the grains are arranged at individually specified locations in accordance with a predetermined pattern, no excess grains will be attached to the substrate and no pores in the matrix between grains will appear, as it does in a conventional plating process when using grains having a conductive coating (US4547998). As recognized by those in the art, a cleaning process is conducted to

promote adhesion of the plated layer, prior to a plating process. The cleaning operation may include plasma cleaning, ultrasonic water rinsing, acid dipping, solvent degreasing, emulsion degreasing, electrolytic degreasing, alkaline cleaning, electrolytic cleaning, etc. In most cases of the present invention, the plating should be conducted in a manner that deposition on tip
5 portions of the coated grains is limited. Such limitation can be accomplished by a number of methods including use of a pulse reverse electroplating, short time application of reverse currents or mechanical abrasions between two periods of plating, use of insulating material (e. g. adhesive) positioned above tips of grains, as well as addition of a leveling agent to the electrolyte. The leveling agent is preferentially absorbed to a high current section (e. g. tip
10 portion of grains) and acts as a resistance to the growth rate of deposit material.

Electroplating is the most common plating method used to bond grains. Though direct current is commonly used, pulse current (e. g. square-wave pulse current with complete current cutoff during intervals between the pulses) or pulse reverse current (e. g. square-wave pulse current with reverse pulses during intervals between positive pulses) can also be used,
15 since they may lead to better surface finishing and higher hardness, wear resistance and toughness. Other methods to improve the properties or growth rate of the deposit material can be used, such as stirring or oscillating the solution by ultrasonic, electromagnetic, or mechanical vibrating, and using additives to the solution such as rare earth elements, metal ions-containing organic or inorganic acid, etc. Compared to electroplating, electroless plating
20 (i. e. chemical plating) produces a more uniformized, and basically harder deposit, especially when experiencing a heat treatment. In addition, by subjecting a substrate to an electroless plating bath while at the same time applying an electrical current through the bath with the substrate as the cathode and an electrode containing the plating metal being positioned in the bath as the anode, improved filling of the spaces between the grains may be achieved, and the
25 shadowing of areas of the substrate by grains can be avoided. For some cases, a thin electroplating layer may be formed on a chemically plated material in order to prevent the generation of cracks or fissures in the chemically plated material that is hardened by a heat treatment.

Notably, an electrically insulating fabric can also get metallic deposit and grains
30 attaching thereto through a plating process without surface metallization of the fabric. For example, an insulating mesh can be laid on top of grains sufficiently embedded in a growing layer on a conductive substrate. After the mesh has been penetrated, the mesh mounted with

grains is removed from the conductive substrate. Advantageously, a homogeneous grain height is achieved. In another example, a nylon mesh can be laid under tension on a smooth electrically conductive surface for deposition of metal into the mesh openings. The conductive surface may be the surface of a cylinder about which the mesh is wrapped or it may be an
5 endless band of stainless steel or other electrically-conductive metal. To get discrete deposits for a flexible article, the conductive surface or the nylon mesh should be covered with an insulating mask having a plurality of openings corresponding to the discrete deposits. When the electrically conductive surface is an endless band the deposition of metal on the mesh material may be a continuous process. Specifically, a roll of the mesh material is laid on the
10 band at one end of an operative run of the band and, as the band is moved through the electrolyte towards the end of said run, the metal deposition takes place with the grains disposed on the mesh surface. As a result, the grains can gradually get embedded in the growing layer which is adhered to the mesh. When the band reaches the end of its run, the mesh material is stripped off the band. Thus the band is able to be passed continuously
15 through the electrolyte bath and a continuous length of the mesh material is applied with the plated metal and grains during its passage. Preferably, arranging grains on the mesh can be accomplished by a transferring method.

In another aspect, the bonding process for arranged grains can be a multi-step process that involves at least one plating step. The plating can be designated to initially affix the
20 grains so that the intended arrangement (e. g. positions/orientation) can be maintained during the process for further bonding the grains, which may include soldering, brazing, welding, thermal spraying, spraying forming, laser cladding, hot dipping, sol-gel, electrophoretic deposition, vitrifying, curing, and combinations thereof. A second plating can also be used to further bond the affixed grains. In curing of a fluid organic material, the bond precursor can
25 be applied to the substrate (mounted with grains through plating) by spraying, showering, dipping, die coating, brushing and the like. The curing methods can be any one known in the art.

In a soldering/brazing/welding process which serves to tightly bond the grains with a matrix material (welding refers to the process during which the coating on grains melts along
30 with the bond precursor), bond precursor is generally available as rod, ribbon, powder, paste, cream, sheet, foil, slurry, dough, metal clay, deformable cake, wire and preforms. A precursor sheet can be a rolled continuous amorphous alloy with a homogenous alloy composition and a

sufficiently low melting point, such as amorphous brazing alloy foil (MBF) manufactured by Honeywell having the NICROBRAZ LM composition. A slurry, dough, paste, metal clay, or a deformable cake can be formed from a mixture of metal powder (or pre-alloyed powder) with a suitable binder (typically burnable organic) and a solvent (e. g. water) by a number of methods such as blending, stirring, tumbling, milling, tape casting, roll milling, extruding, rolling, and others. The mixture may also comprise additives such as an organic plasticizer, a filler for the matrix material, a wetting agent (e.g. menhaden oil, phosphate ester) to prevent the powder from agglomeration, and an oxygen scavenger (e. g. aluminum, calcium, magnesium, and zirconium) to reduce oxidation. The bond precursor can be pre-placed at the desired location or applied during the heating cycle. For example, slurry can be applied to the substrate (mounted with grains through plating) by brushing, spraying, doctoring or dipping, paste can be coated with the aid of a turning machine, and sheet can be attached by adhesive, friction, magnetic force, or the like. There are many heating methods available for fusing the bond precursor, including a soldering iron, a soldering gun, a hot-air pencil, a bath of molten salt (typically NaCl, KCl and other compounds), torches powered by butane, oxyacetylene, propane, a MAPP, acetylene, or propylene, a laser beam, infrared lamp, infrared beam, electron beam, induction heating by high-frequency AC current, resistance heating by passing an electric current through the precursor, blanket, furnace/oven (e. g. batch type, continuous, retort with controlled atmosphere and vacuum), arc, and plasma transferred arc. Flux may be required to prevent oxidation, and it can also be designated to act as a wetting agent and a chemical cleaning agent. Flux may be applied in any number of forms including flux paste, liquid, powder or pre-made pastes that combine flux with metal powder, or by using rods with a coating of flux, or a flux core.

In thermal spraying, "feedstock" (bond precursor) of metals, alloys, ceramics, glasses, plastics and composites in powder or wire form, is heated by electrical (plasma or arc) or chemical means (combustion flame) to a molten or semimolten state and accelerated towards the substrate in a form of micrometer-size particles. Variations include flame spraying, wire arc spraying, plasma spraying, detonation spraying, warm spraying, cold spraying, plasma transferred wire arc thermal spraying and high velocity oxy-fuel coating spraying. Combination of spraying techniques can also be used, for example, flame spraying and plasma spraying may be combined to form a metallurgical bond between deposit and substrate. In spray forming, also known as spray casting or gas atomised spray forming, molten metal

exiting a furnace as a thin free-falling stream is broken up into droplets by an annular array of gas jets, and these droplets accelerated by the gas jets are deposited onto the substrate whilst in a semi-solid condition. In laser cladding, a powdered or wire feedstock material (metal, ceramic, or polymer) is injected into the system by either coaxial or lateral nozzles, melt by a laser and is deposited onto the substrate. In hot dipping (or dip soldering), the substrate is submerged into a molten metal bath, and thus coated with the metal (e. g. tin-lead, tin-zinc, lead-silver, cadmium-silver, zinc-aluminium, tin-silver and tin-bismuth). Uniform coating can be applied onto flat or cylindrical substrates, preferably by spin coating.

To further bond the grains, a sol-gel process can also be used, wherein a colloidal solution (sol) of metal oxides can be deposited on the substrate to form a film (e.g., by dip coating or spin coating). The 'sol' can gradually evolve towards the formation of a gel-like diphasic system. Then a drying process is needed to remove the liquid solvent, followed by a thermal treatment (firing process) to favor further polycondensation and enhance mechanical properties and structural stability. The sol-gel approach is a cheap and low-temperature technique for glass/ceramic coating. In electrophoretic deposition, colloidal particles (including polymers, glass, ceramics and metals) suspended in a liquid medium are deposited onto the substrate attached to an electrode (cathode or anode, depending on the charge the particles carry). After deposition, a baking allows the coating to become smooth and continuous. If an ultrafilter is used, all of the rinsed off materials can be returned to the coating vessel, reducing the amount of waste discharged into the environment. For the deposition of ceramic materials, organic solvents may be used to avoid the electrolysis of water. In a vitrifying process, vitreous enamel is made by fusing powdered glass and then hardening to a smooth, durable coating on the substrate. Its tendency to crack or shatter can be minimized by controlling the thickness and thermal expansions well-matched to the substrate. The key ingredient of vitreous enamel is a highly friable form of glass called frit, commercially available. Frit is typically an alkali borosilicate chemistry, containing smelted-in transition metal oxides such as cobalt, nickel, copper, manganese, and iron that facilitate adhesion to the substrate. Various other additives well known in the art may be added to the vitreous bond, and methods to apply it to a substrate are well known in the art. For example, liquid glazes (slurry) can be applied by dipping, pouring, brushing, painting and spraying.

The plating in a multi-step bonding process for arranged grains may also be designated to initially affix grains to a first substrate which can act as a carrier of grains to form an abrasive article. In some cases (e. g. for a double-sided product), a carrier substrate with its both sides mounted with grains may be advantageous. A porous carrier substrate having a plurality of openings with the grains arranged on the surface of the substrate or in the openings of the substrate, may be preferred. Grains can be retained within the openings by forcing them into the openings smaller than the grains, or by deforming the openings once grains are placed into openings larger than the grains. The porous carrier can be made of metals, metal alloys, plastics, rubber, graphite, and fiber or powder of metal alloy, glass, ceramic and cemented carbides. The porous carrier may be formed of non-woven fabric, woven fabric (e. g. mesh), or wires otherwise fastened together, as by welding or soldering. Further, the porous carrier may take the form of expanded material, punched, perforated or drilled material, extruded material. Moreover, the openings do not necessarily extend completely through the carrier, but may comprise pits that are open only at their tops.

The grains/carrier assembly with the grains temporarily affixed to the carrier substrate can be used to form an abrasive article in several ways. For example, the assembly (preferably flexible) may be attached to a second substrate (in particular a curved substrate) with the carrier facing the second substrate surface, followed by a further bonding process which can be any one of the above-cited, including a plating process (called second plating, same or not as the initial plating). Alternatively, two pieces of the grains/carrier assembly can be attached to each side of a second substrate and a further bonding process completes the production of a cutting tool with the second substrate acting as its hub/core. Additionally, two or more pieces of the grain/carrier assembly can be stacked to form a multi-layer green body which can then be consolidated through sintering or infiltration (to be described later). The carrier substrate may be embedded into the final tool, playing a role as a filler in preventing crack or fracture of the matrix. To maintain the intended grains arrangement (locations/orientations) during a subsequent heating process, a refractory carrier substrate (having high melting point) such as glass, ceramic, metal, carbon, graphite, silica, stainless steel, cobalt, zirconium, titanium, boron, BN, alumina, silicon carbon, tungsten and the like, combined with a refractory affixing material, e. g. produced by the initial plating (e. g. alloys of Ni, Co, W), may be required.

In a further aspect of the present invention, the plating in a multi-step bonding process for arranged grains can also be designated to further bond grains that have been initially

affixed through a non-plating process such as brazing, soldering, welding, spraying, sintering, hot dipping, gluing, and laser cladding. For example, grains can be bonded through a combined process of initial brazing and subsequent plating. In addition, a grains/carrier assembly where grains are initially affixed to a carrier substrate through brazing can be
5 attached to a platable substrate, followed by subsequent plating. Further, a brazed grain/carrier assembly can be strengthened by subsequently plating a refractory material (e. g. Ni, Co, tungsten alloys) thereon when used to make a two/three dimensional product by the methods described above.

Brazing technique used to bond abrasive grains by fusing a brazing material is well
10 known in the art. Brazing material can exist in mechanical/chemical coating on the grains, or in adhesive used to temporarily affix the grains when arranged. A braze sheet made of metal (e.g. an amorphous sheet) or made of metal powder and temporary binder, can be first attached to the substrate and then arranging grains on the sheet, followed by pressing the grains in if necessary. Alternatively, grains can be first arranged and temporarily affixed
15 on/into a braze sheet, prior to attaching them to the substrate. In addition, braze slurry made of metal powder can be applied by a number of methods including spraying, dipping, and the like, to the substrate where the grains are temporarily affixed (e.g. by adhesive). Notably, a reactive element in the brazing material of the present invention is not necessarily required, and heating can be conducted in air and can be localized since the grains are protected by their
20 coatings. A reactive braze (e. g. containing Ti) requires the exclusion of oxygen and high temperature to achieve chemical bonding. In addition, reactive metal (e. g. titanium) can react with other elements in the matrix composition during brazing to form intermetallic compounds which detract from the mechanical properties of braze. Moreover, the intermetallics can adhere braze very strongly to the metal substrate. This adhesion makes
25 stripping of braze from worn out tools more difficult. The ability to recover used cores increasingly affects tool production cost, particularly with respect to large tools for the construction industry, such as large diameter grinding wheels for ferrite.

Advantages of present combined process of brazing and plating over a single brazing process include: a thick braze layer is no longer required since a thick layer may facilitate
30 flow of the brazed material at high temperature and lead to shifting of the intended positions/orientations of the grains; the subsequent plating in the combined process makes it possible for defective sites on the surface of brazing metal layer to be mended. For example,

the unfilled parts of the surface and the gaps between grains and the brazing metals can be filled. Advantages of present combined process over a single plating process include: a stronger adhesion between matrix and grains; a stronger adhesion between substrate and grain bottom where metal ions are difficult to be deposited during electroplating because of the close contact.

Other multi-step processes involving at least one plating step may also be used to bond the arranged grains. For example, an initial brazing, then a plating and a third spraying of a plastic layer, or first brazing, then electroplating, followed by electrophoretic deposition, or first electroplating, then electrophoretic deposition, followed by sol-gel process. In addition, an electrolytic plating of a high-melting-point metal layer (e. g. Ni or Cu alloys), and hot dipping of a low-melting-point metal layer (e. g. Sn-based or Zn-based alloys) can be conducted repetitively to form a layered structure. In this way, there can be formed a diffused layer by allowing Ni, Cu or the like of the high-melting-point metal layer to be diffused into the low-melting-point metal layer, which can take place even below a melting point of the low-melting-point metal. A relatively thin (e. g. 0.02-2 micro meter) layer of high-melting-point metal is effective to improve the wear resistance of the low melting point metal.

Noticeably, the above descriptions have been concerned with a two dimensional abrasive article comprising a single layer of grains, or a double-sided article where grains in single layer are bonded to both sides of a substrate. To obtain a three dimensional article (multi-layer), the steps of arranging grains and bonding the grains can be repeated for desired times, with the surface of a formed layer acting as the substrate for a new layer. To improve the adhesions of layers heat treatment is an option.

Additionally, by assembling two or more pieces of above-described grains/carrier assembly, a multi-layer product can be formed. Layers can be substantially alike, but of course may differ in type, concentration and size of grains, as well as type and size of carrier substrate, and also type and composition of matrix material. By varying these factors, one can control the rate and profile of wear. The layers can be consolidated together by brazing, sintering, infiltration, sol-gel process, plating, hot pressing, gluing, and combinations thereof. For example, a number of grains/carrier assembly can be combined with powders of metal, amorphous metal, plastic, glass, or ceramic, to form a two/three dimensional green body which can be consolidated by sintering. Specifically, a grains/carrier assembly and matrix

powder can be combined to form a sheet through pressing, rolling, tape casting, laminating the assembly with a soft easily deformable flexible material (SEDF) comprising matrix powder, or the like, and then a number of such sheets can be stacked to form a three-dimensional green body. Pressing (e.g., axially within a mold or die, or substantially isostatically within a mold or container) may be needed. During this molding operation, pressure can be released several times for letting gas generated from the sheets out of the mold. When sheets carrying abrasive grains are too thin to afford the grains with an adequate axial distance for the distribution thereof or when the sheets can not provide a sufficient amount of matrix, they can be piled in layers with filler sheets or powders one after the other. A wholly sintered abrasive tool is made by putting a steel core together into the mold and then sintering it.

The green body may be machined or otherwise shaped to form features such as blades, fluid courses, internal longitudinal bores, cutting element pockets, etc., prior to sintering/infiltration. In some embodiments, the green body (with or without machining) may be partially sintered to be machined or otherwise shaped prior to final sintering/infiltration. The sintering process may be conducted by a number of methods known to one of ordinary skill in the art, such as conventional sintering in a furnace, spark plasma sintering, microwave sintering, solid state or liquid phase sintering, high-temperature, high-pressure press (HTHP) process, the Rapid Omnidirectional Compaction (ROC) process, the CERACON.RTM process, hot isostatic pressing (HIP), or adaptations of such processes. High-speed sintering involves passing high electrical current in a manner that most of the energy serves for densification of the compact.

Infiltration can also be used to consolidate the three dimensional green body. An infiltrating material in a form of particle, chunk, preformed disc or foil may be placed on top of the green body. Alternatively, an infiltrating material may be contained in or laminated with the individual sheet in the green body. The green body is then heated sufficiently to melt the infiltrant and allow it to flow into the spaces between grains and therefore, the grains get bonded. In some embodiments, pressure applied to the molten material and an atmosphere having a reduced oxygen partial pressure may facilitate the infiltration process. Coarse grains and shorter infiltration path may also assist in infiltration. Most commonly used infiltrants are copper based alloys such as Cu-Mn, Cu-Mn-Ni, and Cu-Si, and cobalt, tin, nickel, iron, or

aluminum based alloys such as Ni-Si, Al-Si, and Nicrobraz LM (Ni-Cr-B-Si-Fe) alloys manufactured by Wall Colmonoy Company (U.S.A.).

Alternatively, a number of the grains/carrier assemblies can be first structured to form a three dimensional skeleton, and then fill it with precursor sol, preferably within a mold, and
5 subsequent drying and firing will form a bond for the grains. Other infiltrant can also be used such as liquid organic material and molten metal.

Compared with the present sintering and infiltration methods where the grains are temporarily affixed by a refractory bond to a refractory carrier substrate, both conventional sintering and infiltration methods find it difficult to maintain the intended grains arrangement
10 (positions/orientation) in a green body during heating process because of flow of the molten material and density difference between grains and molten material (leading to grain floating, for example).

In yet another aspect of the present invention, a bonding process for arranged grains can not necessarily involves a plating process. For example, the process can comprise first
15 temporarily affixing the grains to a porous substrate by a method such as soldering, brazing, welding, spraying, plasma spraying, laser cladding, hot dipping, sol-gel, electrophoretic deposition, vitrifying, gluing, a force of magnetism, forcing the abrasive grains into the porous substrate, deforming the openings of the substrate, and combinations thereof. For example, metal/glass/resin powder or the like is placed into each opening of a mesh carrier,
20 surrounding the grains. The powder can be sintered/vitrified/cured to secure the grains in place. Thereafter, the abrasive grains temporarily affixed to the porous substrate can be used as a grains/carrier assembly to produce an abrasive article by methods the above recited, during which the abrasive grains substantially remain affixed to the porous substrate. In the resultant product (flexible, double sided, surface curved, or multi-layered), abrasive grains are
25 substantially precisely located as desired.

Following the bonding process, a portion of the matrix material may be removed to better expose the cutting edges of the grains. The removal may be accomplished by any known method including chemical etching, electrolytic processing (e. g. electro-polishing), sand blasting, dressing with a conventional grinder or with free particles of an abrasive,
30 lapping wherein protruded tips of grains are cut by using a diamond abrasive. In a later step, the produced tool can be edged, finished, speed-tested or balanced. For example, the product may be finished using conventional techniques (e. g. grinding and OD/ID finishing) to ensure

that size and shape are within desired tolerances, and double-side lapping to insure that the exterior surface flatness and thickness are within desired tolerances. In a flexible article wherein discrete matrix nodules are bonded to a fabric, the lateral movement of the nodules and their tendencies to chip off can be dramatically reduced by filling the interstices between the nodules, with a resin (e. g. polyurethane), or a filled resin (i.e. a resin filled with silicon carbide powder).

In addition, heat treatment can serve to provide a stronger bond, to harden and toughen the matrix and relax stresses.

Further, a relatively thin layer of a friction reducing or lubricating material can be added over the top of the bond material. For example, if a very thin layer of chromium or chromium-containing cobalt alloy is electrolytically deposited on a plated diamond cutting disc used to dice siliceous materials such as quartz, sapphire, garnet, alumina and glass, adherence of the siliceous debris to the cutting disc can be markedly decreased, leading to increased quality of the finished work product and overall service life of the tool. The friction reducing material can be a composite material comprising polytetrafluoroethylene, molybdenum disulfide, mica, graphite and fluorocarbon resins. In a preferred embodiment, the composite material is a nickel/phosphorous alloy material having micron-sized Teflon particles. Additionally, a thin coating of anti-corrosive material may be used to protect the grains and the matrix, and reduce their susceptibility to chemical attack from the chemicals of the abrasive slurry, especially those slurries containing acids. In a particular embodiment, the anti-corrosive layer is comprised of at least about 90-95% diamond, diamond-like-carbon or CBN, produced by a physical vapor deposition (PVD) method such as cathodic arc method.

It should be noted that the substrate to which the grains are arranged can be removed following the bonding process, and the exposed surface can function as the working surface of the abrasive article. In this manner, the substrate effectively serves as a mold. The removable substrate may be made from any soft, deformable material with a relatively uniform thickness, such as rubbers, plastics, waxes, graphite, clays, tapes, foils, metals, powders, resinous material, moldering material, and combinations thereof. The substrate may be a rolled sheet comprising a metal or other powder and a binder. The removal of the temporary substrate can be conducted by peeling, grinding, sandblasting, scraping, rubbing, abrasion, chemical and/or electrolytical dissolution, etc. The substrate material can be selected (e.g., graphite, aluminum, stainless steel, chemically soluble material and low melting point material) or treated (e. g.

passivated) to facilitate the removal of the substrate. The substrate surface may be previously treated with a release material, for example conductive adhesive or automobile wax applied to a platable substrate.

There are several advantages in removing the substrate. First, grains can be
5 sufficiently exposed without further processing after removing the substrate in which the grains are partially embedded, for example, by pressing. Similarly, if the removable substrate is first coated with a thin zinc layer, and then copper and grains are plated followed by nickel plating, grains can be exposed following the removal of the substrate and copper layer. Second, substantially uniform protrusion height of grains over the working surface can be
10 accomplished simply by arranging the grain tips in a co-planar manner, e. g., on a rigid, flat surface of a removable substrate. Third, the removable substrate may be designed to improve the grains orientation. For example, forming a plurality of orienting pits/holes may help to align the abrasive grains such that the tips of individual grain will protrude from the final working surface. In addition, pressing grains onto a very smooth substrate may help to align
15 grains with their flat surface parallel to the substrate. Finally, projections on a removable substrate can serve as a mold to make concave portions (e. g. dimple, ditch or groove) on the final product surface. An example of such projections is an electrically insulating cyanoacrylate gel instant glue formed on a platable substrate by using a delivery device such as commercially available device commonly known as a dispenser which has a cylindrical or
20 tubular nozzle that can be manually operated or controlled by numerical control. Similarly, concave portions on a removable substrate can be translated into protrusions on the final working surface (see FIG. 4, FIG. 5, and FIG. 6).

To facilitate its use, a backing may be coupled to the final abrasive article. For example, a metal abrading disc which is sufficiently thin may be attached to an outer rigid
25 backing and an intermediate elastomeric backing that functions to absorb energy and dampen standing waves thereby providing a cleaner straight line cut and minimizing chipping of the work piece. A flexible abrasive article can be utilized in various forms, simply by cutting into desired shapes, such as strips for abrading belts, rectangles for hand laps, discs, annular shapes etc. A flexible article is usually bonded to a backing. The backing can be rigid like a
30 metal or plastics plate, or it can be flexible like cloth, paper, film, foils, fabrics, screens, perforated sheets, non-wovens or vulcanized fiber. With such a backing, the mechanical properties of a flexible abrasive article can be controlled, e.g. to produce a highly flexible,

semi-flexible or rigid abrasive member. A flexible backing may be in the form of belt, disc, sheet, pad, roll, ribbon or other shape used, e.g., for coated abrasive (sand paper) tools. The backing may be of a material having suitable heat conductive properties to avoid high temperature developed during use, such as copper, or heat conductive material may be
5 integrated in the backing, for example in the form of copper powder, shredded copper or copper strings. A heat conductive material (e. g. graphite) may also be coated on one or both surfaces of the backing. It may be desirable to laminate flexible mesh fixedly mounted with grains on both sides of a backing. This sandwich construction is capable of cutting edgewise into materials like glass, and can be conveniently formed into other articles such as core drill
10 bit, endless cutting belt, and the like.

The coupling may be facilitated by roughing the contact surfaces between the backing and the abrasive article, for example, by grains blasting or mechanical abrading. In addition, primers such as 3M 901 Silane Primer, Loctite SIP (self-indicating primer), Bostick 9253 primer, and Ciba Geigy DZ81 acid etch primer can be employed to enhance the bond. The
15 coupling can be accomplished by means of an appropriate fixative (e.g., conventional brazing, soldering, laser welding, sintering, hot pressing, electroplating, gluing or cementing). For example, a sheet carrying grains may be embedded in a backing by extrusion or by pressing the sheet into the backing, i.e. by vulcanization. A sheet may be coated or sprayed with permanent substrate material or a sheet can be dipped into molten backing material or simply
20 adhered to the backing with solvent or adhesive. Organic adhesive can be used, including pressure sensitive adhesives, hot-melt adhesive (e. g. polyester), and two-part, cross-linkable adhesive (e. g. polyurethane, epoxy resin, and phenol resin). Epoxy-acrylate resins provide improved bonding between metal and backing. Some additives can be selected from inorganic compounds including silicon carbide, boron carbide, alumina, selenium oxide and so on, and
25 metallic powders including copper powders, iron powders and so on.

In some instances, a metallic adhesive can be used to withstand much higher loads and increase water resistance, heat resistance and solvent resistance. The metallic adhesive can be a metal solder such as alloys of tin and lead. Vapor heating or vapor phase reflow solder heating can be used to minimize any potential degradation of the backing, such as vapor bath
30 formed using a perfluoroalkyl tertiary monoamine liquid (e. g., Fluorinert FC-70 commercially available from the 3M Company, St. Paul, Minn). To provide a stronger bond, the metallic adhesive can also be a brazing metal or alloy. Brazing paste alloys are

particularly suitable. Examples of brazing metals include copper, iron, aluminum, nickel, cobalt, and their alloys. A laser can be used to melt and combine the metal of a segment and a steel substrate creating a stronger weld, which can hold the segment even in high temperatures. Notably, an integrate multi-layer product (e. g. grinding stone and cutting segments) can be
5 made by piling in layers a desired number of sheets fixedly mounted with abrasive grains, and organic/metallic adhesive applied between layers, then subjecting the assembly to a warm or hot pressure.

The present invention will be described more specifically with reference to examples
10 in the following. However, the present invention is not limited to the examples.

Examples

Example 1

A stainless steel disc (120D-0.65T) that is about 120 mm in diameter and about 0.65 mm in thickness is partially covered by an electrically non-conductive template having a
15 plurality of apertures distributed in a lattice pattern. The template covers a generally circular area on a central portion of the disc of about 100 mm in diameter, leaving a width of about 10 mm around the perimeter of the disc. The perimeter area is covered by an insulating material to prevent deposition. The aperture separation measuring from the approximate center points of adjacent apertures is about 800 microns with each aperture about 400 microns in diameter.
20 Nickel coated diamond particles with an average size of 300 microns are then dispersed into the apertures so that each aperture accommodates only a single grain. The excess diamond grains are discarded by brushing, titling, vibrating, shaking, etc. The located diamond grains are bonded to the steel substrate by an electroplating process. A 99.99% electrolytic nickel sheet contained in a titanium mesh basket is used as the soluble anode. The electrolytic
25 solution is prepared by the following constituents: nickel sulfate (300 g/l), nickel chloride (40 g/l), boric acid (40 g/l), saccharin (1.0 g/l), sodium laurel sulfate (0.05 g/l), cobalt sulfate (10 g/l) and 1, 4 butynediol (0.7 g/l). As the nickel builds in a layer on the steel substrate, the diamond particles eventually become surrounded by and embedded in the nickel layer. The thickness of the electroplated coating is controlled by the current density and electroplating
30 time. The depth of the layer may be from about 1/3 to 2/3 of the average diameter of the diamond grains. After plating, the deposit is immediately rinsed with running water and dried with hot air. The insulating material and the template are then removed. After removing an

upper portion of the plated material, a grinding disc comprising the steel substrate and the diamond grains bonded by electrodeposited nickel is ready for use.

Example 2

The process of Example 1 is followed, except the diamond grains used in the present
5 example are naked (with no metallic coating) and magnetically sensitive as a result of
containing inclusions of catalysts such as nickel, cobalt, iron, manganese, or like. These
grains are normally excluded in fabrication of electroplated diamond tools because they lead
to the formation of nodules around diamond grains, over-plating of the grains, and pores in
plated material between grains. Individual placement of the grains in the present invention
10 successfully prevents the formation of such pores which are detrimental to the abrasive
retention.

Example 3

A substrate metal having a shape and a dimension of 240D-20T is prepared from
stainless steel (SUS304) by working using a lathe. Then, the substrate surface is covered by
15 an electrically non-conductive template, and the other part is masked with an insulation tape.
The template has apertures in grid pattern with aperture diameter of 200 microns and aperture
separation of 400 microns. The substrate is then treated for degreasing with an alkali and
dipped into a pretreatment fluid containing 240 g/liter of nickel chloride and 100 g/liter of
hydrochloric acid. The dipped substrate is set to an anode and electrolytically etched under a
20 current density of 10 A/dm² at an ordinary temperature for 2 minutes. Then, the substrate
is set to a cathode, and strike plating is conducted for 3 minutes. The treated substrate is
plated in a plating bath of nickel sulfamate under a current density of 1 A/dm² for 15
minutes to form a thin plating underlayer. The purpose of the early plating before placing
grains is to avoid direct contact of diamond grains with the steel base and increase adhesion of
25 the coating layer with the steel. More importantly, a longer period of early plating before
placing the grains makes it possible for the grains to stand on a base above the working
surface of the resultant tool, leading to a better cutting ability of the tool.

Then, diamond grains having an average diameter of 149 microns are placed on the
substrate surface. The diamond is coated with 0.5 micron of titanium and then with nickel,
30 followed by heat treated at 700 degree Celsius for 30 minutes to increase bonding strength.
After the diamond abrasive present in the excess amount is removed by shaking, the obtained
combination is electroplated by using a plating bath of nickel sulfamate containing additives

for adjusting the plating stress and the hardness under a current density of 0.5 A/dm.² to affix the diamond abrasive to the substrate metal. Afterwards, the template is removed, and consequently, the diamond grains form a grid pattern on the substrate with an inter-diamond pitch of 400 microns. Subsequent plating in the same plating bath of nickel sulfamate under a current density of 1 A/dm.² forms a plating layer for tightly bonding the abrasive grains. Finally, the mask is removed, and the resultant product is worked for the abrasive protrusion by chemical etching or by lapping of a diamond grinder to obtain a dresser.

Example 4

Diamond grains having an average size of about 65 microns are coated with multiple layers to form an exterior of about 120 microns. The coated diamond grains are positioned with a template on a 45D-0.1T flat stainless sheet attached to a plastic plate. On the template, 5 concentric circles having diameters increasing at a pitch of 0.5 mm from 44 mm to 42 mm are drawn and straight lines are drawn through the center of the circle at an angle between the adjacent lines of 1.5 degree. Apertures of 200 microns in diameter are arranged at intersections of the circles and the straight lines. Other portion of the stainless sheet is covered by an insulating material. After affixing the diamond grains by plating, the template is removed leaving diamond particles on the substrate in the pattern dictated by the template. Then, electroplating continues. Once the nickel layer has been completed, a conventional grinding wheel with silicon carbide is used to grind the surface of the plated material. Subsequently, the plated layer and substrate sheet are separated. The final product is a cutting disc with a thickness of 0.07 mm and a diameter of 45 mm.

Example 5

A stainless steel sheet having a thickness of 150 microns is covered with a template having a diameter of 120 mm. On the template, a square grid having a distance between grid lines of 600 microns is assumed to be formed and apertures having a diameter of 300 microns are formed at the intersections of the grid lines. Then pits are formed in areas of the substrate corresponding to the apertures. The pits have a shape of a bowl in which the diameter continuously increased from the bottom to the upper face of the substrate sheet. Following pretreatment, the steel substrate is dipped into a plating bath for an early plating. With the plating going on, coated diamond grains having an average diameter of 200 microns are placed in the apertures in a manner such that one grain is placed in each aperture and seat in the corresponding pits. After affixing of the diamond grains to the pits of the steel sheet, the

template is removed. Then, the sheet having the abrasive grains is dipped into another plating bath of nickel sulfamate so that a plating layer having a thickness of about 250 microns is formed. The steel sheet having the plated layer is taken out of the plating bath. Then the sheet is peeled and newly exposed surface will be the working surface of the final tool. After
5 adhering of the finished abrasive article to a stainless steel backing of 120D-12T with an epoxy adhesive, a CMP conditioner comprising diamond grains greatly protruded is completed.

Example 6

This example relates to making products having non-planar shape of working surface,
10 for say profile grinding wheels, cylindrical grinding wheels, reamers, and wire saw beads. First, arranging and affixing grains on a planar first substrate of thin sheet by a first plating, then attaching the substrate sheet mounted with the stuck grains to a second substrate with a desired shape before a second plating to permanently bond the grains.

15 By the use of previously coated abrasive grains, the present invention provides ways to the desirable combination of chemical bonding and precise placement of grains in abrasive products, in particular, plated products, compared to the conventional products where naked grains are randomly placed and/or merely mechanically anchored. Further, products of the present invention may have a matrix with a layered structure, e. g. an inner brazed layer and
20 an outer plated layer, an inner plated layer and an outer resinous layer, an inner brazed layer and a medium plated layer and an outer resinous layer. Furthermore, a grains/carrier assembly of the invention mounted with grains can be used to achieve precise positioning of grains in sintered, brazed, infiltrated, vitrified or resinous products, in particular in a three dimensional body (i.e. multi-layered product). Additionally, by using coated abrasive grains, the present
25 invention provides ways to reducing thermal damage to the grains (e. g. diamond) during heating (e. g. sintering, brazing, and infiltration), to allowing the use of localized or selective area heating and simple bond material. Localized or selective area heating (e. g. laser, infrared, or electron beam heating) can avoid significantly raising the temperature of the green body and avoid the formation of cracks. Localized area heating methods also present the
30 opportunity to create intermittent abrasive coating including precise patterns of bond material and abrasive grains. In such case, unbrazed material can be removed, for example by brushing, shaking or air-jetting the wire.

This invention may also be applicable to other applications not related to making abrasive tools, for example, hardfacing which may be applied to a new part during production to increase its wear resistance, or may be used to restore a worn-down surface. The result of significant savings in machine down time and production costs has meant that this process has
5 been adopted across many industries such as steel, cement, mining, petrochemical, power, sugar cane and food. Hardfacing is frequently used to extend the service life of drill bits and other downhole tools used in the oil and gas industry. Additionally, the present abrasible coating technique can be employed in the compressor and turbine sections of gas turbine engines to not only increase the efficiency of the compressor, but to also provide a relatively
10 speedy and inexpensive method for restoring excessively worn turbine engine parts to service. In normal use, abrasively tipped blades show wear, erosion, and actual breakage at the points where the blade tip surface intersects the leading edge and the trailing edge of the blade. Further, since the weight of abrasive layer imposes stresses on the blade substrate during use, it is highly desirable that the minimum thickness of abrasive layer be applied. Furthermore,
15 since blades are finished to length tolerances of 0.05 mm or less, both the preparation of the substrate and the application of the abrasive layer must be carried out with high precision. The present invention provides a solution by creating an abrasive layer containing a single layer of grains with desirable abrasive retention, controlled abrasive arrangement, uniformly protruded abrasive height and specifically reinforced areas.

20 It is to be understood that the above-referenced description, exemplary embodiments illustrated in the drawings, specific language, terminology, examples, arrangements are illustrative of the application for the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are
25 intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function, process step, inventive feature,
30 additional application of the principles of the invention, manner of operation, assembly, and use may be made without departing from the invention as set forth in the claims.

CLAIMS

What is claimed is:

1. An abrasive article, comprising a plurality of abrasive grains that are arranged at
5 individually specified positions in accordance with a predetermined pattern, and are
chemically bonded with a matrix material that at least partially comprises a plated material.
2. The abrasive article of claim 1, wherein the abrasive grains include at least one member
selected from the group consisting of diamond and cubic boron nitride.
- 10 3. The abrasive article of claim 1, wherein the working surface of the abrasive article has
protrusions regularly arranged in accordance with a predetermined pattern, and each of the
protrusions is sufficient in size enough to accommodate at least one abrasive grain.
- 15 4. The abrasive article of claim 3, wherein the upper surface of each protrusion is substantially
flat.
5. The abrasive article of claim 3, wherein the protrusions are sufficient in size enough to
accommodate at one smaller protrusion which is sufficient in size enough to accommodate at
20 least one abrasive grain.
6. The abrasive article of claim 1, wherein the predetermined pattern defines at least one
member selected from the group consisting of abrasive grain position, abrasive grain
orientation, abrasive grain size, and abrasive grain protrusion height above the working
25 surface of the abrasive article.
7. The abrasive article of claim 1, wherein the predetermined pattern is a three dimensional
pattern.
- 30 8. The abrasive article of claim 1, wherein the predetermined pattern is a member selected
from the group consisting of a substantially uniform pattern, a non-uniform pattern providing
at least one specified area that wears more slowly than a remainder, and a combination

thereof.

9. The abrasive article of claim 1, wherein the abrasive grains on the working surface of the abrasive article are oriented in a direction with their sharp points extending away from the
5 working surface of the abrasive article.

10. The abrasive article of claim 1, wherein the abrasive grains on the working surface of the abrasive article protrude above the working surface of the abrasive article to a substantially uniform height.

10

11. The abrasive article of claim 1, wherein the matrix material comprises at least one member selected from the group consisting of an electroplated material, an electroless plated material, a braze, a solder, a sintered material, an infiltrant, an organic material, and a vitrified material.

15

12. The abrasive article of claim 1, wherein the matrix material has a layered structure.

13. The abrasive article of claim 1, wherein the matrix material is discontinuous.

20 14. The abrasive article of claim 1, wherein the matrix material includes a filler material selected from the group consisting of a ceramic powder, a fiber, a mesh, a sheet having blind holes or through holes, a solid lubricant and a combination thereof.

25 15. The abrasive article of claim 1, wherein the plurality of abrasive grains are bonded to at least one portion of a substrate.

16. The abrasive article of claim 15, wherein the substrate surface has concave portions selected from the group consisting of blind holes, through holes, grooves, spaces between projected portions, and combinations thereof.

30

17. The abrasive article of claim 15, wherein the substrate is selected from the group consisting of a flexible substrate, a perforated substrate, a mesh, a platable substrate, a

substrate having a substantially flat surface, and a substrate having a contoured surface.

18. The abrasive article of claim 1, which is a tool or a segment of a tool, wherein the tool is selected from the group consisting of a CMP pad conditioner, a core drill bit for construction
5 or exploration, a wire saw bead, a reciprocating tool, a flexible tool, and a profiler.

19. A method for making an abrasive article, comprising the steps of:

- a) providing a plurality of abrasive grains;
- b) coating each of the plurality of abrasive grains with a coating layer that chemically
10 bonds to each of the plurality of abrasive grains;
- c) arranging the plurality of individually coated abrasive grains on or in the surface of a substrate at individually specified positions in accordance with a predetermined pattern; and
- d) chemically bonding the plurality of individually coated abrasive grains with a matrix material through a bonding process involving plating.

15

20. The method of claim 19, wherein the abrasive grains include at least one member selected from the group consisting of diamond and cubic boron nitride.

21. The method of claim 19, wherein the step of coating each of the plurality of abrasive
20 grains is carried out by a method selected from the group consisting of chemical vapor deposition (CVD), physical vapor deposition (PVD), electroless plating, electroplating, sintering, sputtering, brazing, salt bath deposition, thermal pyrolysis, a sol-gel process, a fluidized bed process, and a combination thereof.

22. The method of claim 19, wherein the coating layer on the abrasive grains includes at least
25 one material selected from the group consisting of a metal, an alloy, a metallic composite material, a metal oxide, a metal oxide precursor, and an organometallic coupling agent.

23. The method of claim 19, wherein the coating layer on the abrasive grains has a layered
30 structure.

24. The method of claim 19, wherein the coating layer on the abrasive grains comprises at

least one member selected from the group consisting of a wetting layer and a layer having a rough surface.

25. The method of claim 19, wherein the substrate surface has concave portions selected from
5 the group consisting of blind holes, through holes, grooves, spaces between projected portions, and combinations thereof.

26. The method of claim 25, wherein the concave portions have at least one capability
10 selected from the group consisting of positioning abrasive grains and orienting abrasive grains.

27. The method of claim 25, wherein the concave portions are formed by a method selected
from the group consisting of mechanical process, chemical process, electrochemical process,
photochemical process, molding process, and combinations thereof.

15

28. The method of claim 19, wherein the substrate is selected from the group consisting of a
flexible substrate, a perforated substrate, a mesh, a chemically soluble substrate, a soft
deformable substrate, a platable substrate, a substrate having a substantially flat surface, and a
substrate having contoured surface.

20

29. The method of claim 19, wherein arranging the plurality of individually coated abrasive
grains includes at least one member selected from the group consisting of positioning the
abrasive grains having a specified size at individually specified positions, orienting the
abrasive grains, and controlling the abrasive grains' protrusion height above the working
25 surface of the final abrasive article.

30. The method of claim 19, wherein the predetermined pattern is a member selected from the
group consisting of a substantially uniform pattern, a non-uniform pattern providing at least
one specified area that wears more slowly than a remainder, and a combination thereof.

30

31. The method of claim 19, wherein the step of arranging the plurality of individually coated
abrasive grains is carried out by using a template having a plurality of apertures.

32. The method of claim 31, further comprising the step of removing the template mechanically or chemically.

5 33. The method of claim 31, wherein the apertures are formed by a method selected from the group consisting of mechanical process, chemical process, electrochemical process, photochemical process, molding process, screen printing, and combinations thereof.

10 34. The method of claim 19, wherein the step of arranging the plurality of individually coated abrasive grains is carried out by using adhesive droplets.

15 35. The method of claim 34, wherein the adhesive droplets are formed by a method selected from the group consisting of screen printing, jet printing, using a micro-dosing system, using an array of needles, transferring, spraying, covering or removing unwanted adhesive, and combinations thereof.

36. The method of claim 19, further comprising the step of temporarily affixing the plurality of individually coated abrasive grains to the substrate prior to the bonding process,

20 37. The method of claim 36, wherein the affixing is accomplished by a method selected from the group consisting of an adhesive, an adhesive containing metal powders or glass powders, a force of magnetism, friction, and combinations thereof.

25 38. The method of claim 19, wherein the step of arranging the plurality of individually coated abrasive grains is carried out by transferring a plurality of individually coated abrasive grains that is temporarily affixed to a transfer, to the substrate.

30 39. The method of claim 38, wherein the plurality of individually coated abrasive grains is temporarily affixed to the transfer by a method selected from the group consisting of continuous adhesive, discontinuous adhesive, a force of magnetism, friction, and combinations thereof.

40. The method of claim 38, wherein the transfer is selected from the group consisting of a flexible transfer, a perforated transfer, a mesh, a transparent transfer, a chemically soluble transfer, a soft deformable transfer, a transfer having a substantially flat surface, and a transfer having a contoured surface.

5

41. The method of claim 38, wherein the transfer surface has concave portions selected from the group consisting of blind holes, through holes, and combinations thereof.

42. The method of claim 41, wherein the concave portions have at least one capability selected from the group consisting of positioning abrasive grains and orienting abrasive grains.

10

43. The method of claim 38, further comprising the step of removing the transfer mechanically or chemically.

15

44. The method of claim 19, wherein the plating is selected for the group consisting of electroplating, electroless plating, and a combination thereof.

45. The method of claim 19, wherein the bonding process is an electroplating process.

20

46. The method of claim 19, wherein the plating is conducted by applying a current selected from the group consisting of direct current, pulse current, reverse current, pulse reverse current, and combinations thereof.

47. The method of claim 19, wherein the plating is conducted in a manner that deposition on the tip portions of the abrasive grains is limited.

25

48. The method of claim 47, wherein the limitation of deposition is accomplished by an insulating material positioned above the tips of the abrasive grains.

30

49. The method of claim 48, wherein the insulating material is selected from the group consisting of a continuous material, a discontinuous material, a mesh, and a perforated

material.

50. The method of claim 19, wherein the bonding process is a multi-step process and the plating involved is designated to initially bond the plurality of individually coated abrasive
5 grains to the substrate, prior to further bonding of the abrasive grains.

51. The method of claim 50, wherein the further bonding of the abrasive grains is accomplished by a method selected from the group consisting of a second plating, soldering, brazing, welding, thermal spraying, spraying forming, laser cladding, hot dipping, sol-gel
10 process, electrophoretic deposition, vitrifying, curing, and combinations thereof.

52. The method of claim 50, further comprising the step of attaching the substrate mounted with the plurality of individually coated abrasive grains through the plating, to a second substrate, prior to further bonding of the abrasive grains.

15

53. The method of claim 19, wherein the bonding process is a multi-step process and the plating involved is designated to further bond the plurality of individually coated abrasive grains that have been initially bonded to the substrate.

20 54. The method of claim 53, wherein the plurality of individually coated abrasive grains are initially bonded to the substrate by a method selected from the group consisting of brazing, soldering, welding, spraying, plasma spraying, gluing, laser cladding, hot dipping, and combinations thereof.

25 55. The method of claim 53, further comprising the step of attaching the substrate mounted with the plurality of individually coated abrasive grains to a second substrate, prior to the plating.

30 56. The method of claim 19, further comprising the step of repeating the steps (a) to (d) to form a multi-layer body with the surface of a formed layer acting as the substrate for a new layer.

57. The method of claim 19, further comprising the step of assembling two or more pieces of the substrates mounted with the plurality of individually coated abrasive grains to form a multi-layer body.
- 5 58. The method of claim 57, wherein the multi-layer body is consolidated by a method selected from the group consisting of sintering, infiltration, sol-gel process, hot pressing, gluing, and combinations thereof.
59. The method of claim 57, wherein the substrate material and the plated material are
10 refractory.
60. The method of claim 57, wherein the substrate is selected from the group consisting of a flexible substrate, a mesh, and a substrate having a plurality of blind holes or through holes.
- 15 61. The method of claim 19, wherein the matrix material includes a filler material.
62. The method of claim 19, further comprising the step of heat treatment.
63. The method of claim 19, further comprising the step of applying a relatively thin layer
20 over the top of the matrix material, wherein the thin layer material is selected from the group consisting of a friction reducing material, a lubricating material, an anti-corrosive material, and combinations thereof.
64. The method of claim 19, further comprising the step of removing the substrate.
25
65. The method of claim 64, further comprising the step of coupling a backing to the abrasive article.
- 66 A method for making an abrasive article, comprising the steps of:
30 a) providing a plurality of abrasive grains;
 b) coating each of the plurality of abrasive grains with a coating layer that chemically bonds to each of the plurality of abrasive grains;

c) arranging the plurality of individually coated abrasive grains on or in the surface of a porous substrate at individually specified positions in accordance with a predetermined pattern, wherein the porous substrate comprises a plurality of openings;

d) affixing the plurality of individually coated abrasive grains to the porous substrate so that the arrangement of the abrasive grains can be substantially maintained during later process; and

e) chemically bonding the plurality of individually coated abrasive grains with a matrix material through a bonding process, during which the abrasive grains substantially remain affixed to the porous substrate.

10

67. The method of claim 66, wherein the porous substrate is selected from the group consisting of a flexible substrate, a mesh, and a substrate having a plurality of blind holes or through holes.

15

68. The method of claim 66, wherein the porous substrate material and the material designated to affix the plurality of individually coated abrasive grains to the porous substrate are refractory.

20

69. The method of claim 66, wherein the affixing step is accomplished by a method selected from the group consisting of electroplating, electroless plating, soldering, brazing, welding, spraying, plasma spraying, laser cladding, hot dipping, sol-gel, electrophoretic deposition, vitrifying, gluing, a force of magnetism, forcing the abrasive grains into the openings of porous substrate, deforming the openings of the substrate, and combinations thereof.

25

70. The method of claim 66, wherein the bonding step is accomplished by a method selected from the group consisting of electroplating, electroless plating, soldering, brazing, welding, thermal spraying, spraying forming, laser cladding, hot dipping, sol-gel, electrophoretic deposition, vitrifying, curing, and combinations thereof.

30

71. The method of claim 66, further comprising the step of attaching the porous substrate affixed with the plurality of individually coated abrasive grains to a second substrate, prior to the bonding process.

72. The method of claim 66, further comprising the step of assembling two or more pieces of the porous substrates affixed with the plurality of individually coated abrasive grains, to form a multi-layer body prior to the bonding process.

5

73. The method of claim 72, wherein the bonding process is accomplished by a method selected from the group consisting of sintering, infiltration, sol-gel process, hot pressing, gluing, and combinations thereof.

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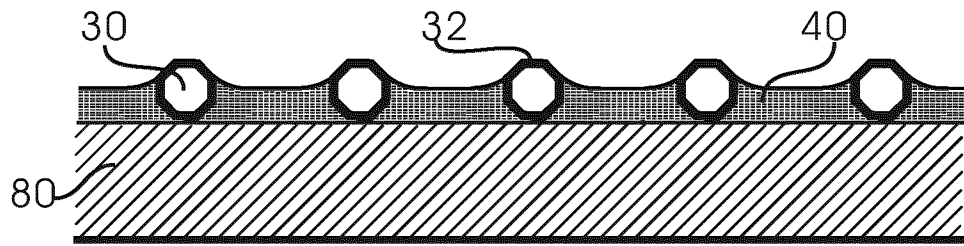


FIG. 1

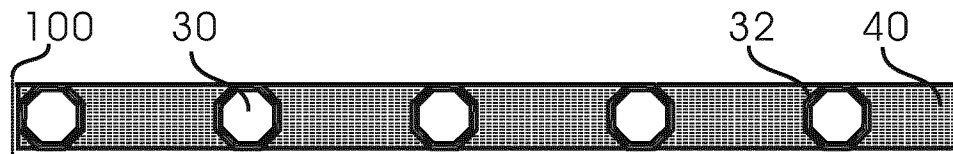


FIG. 2

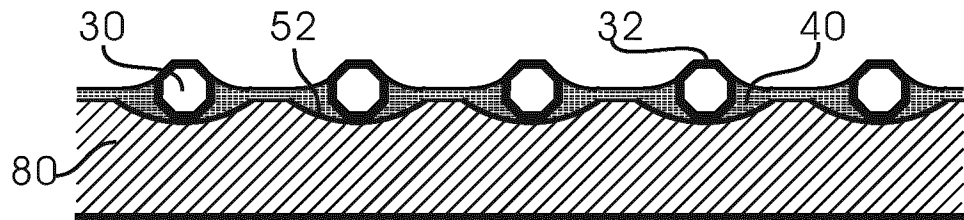


FIG. 3

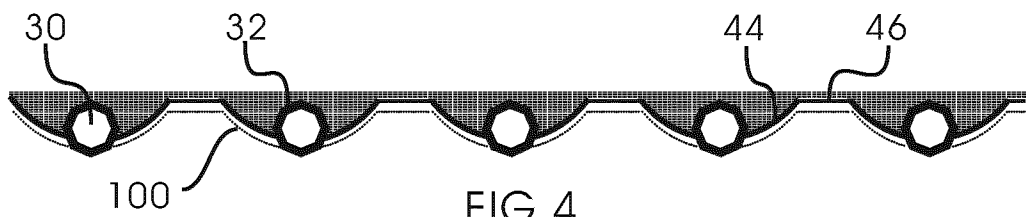


FIG. 4

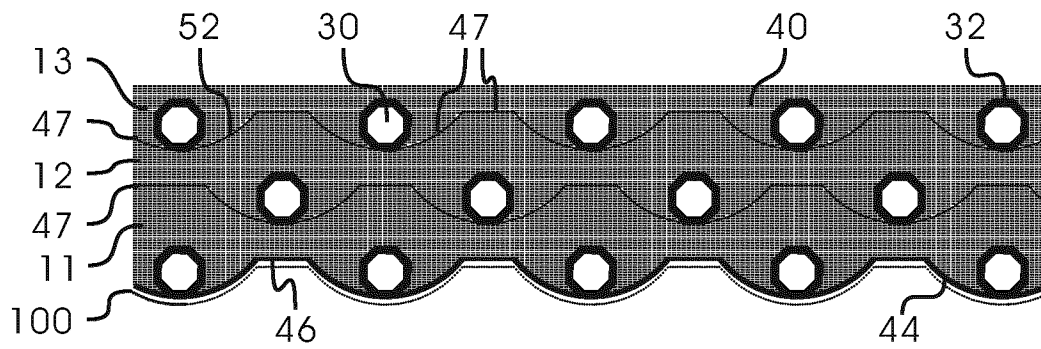


FIG. 5

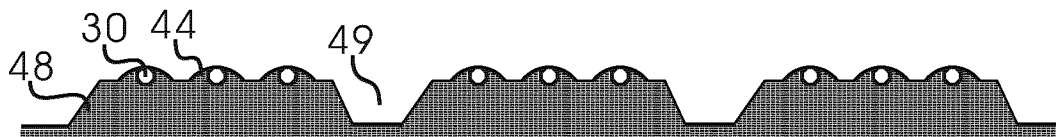


FIG. 6

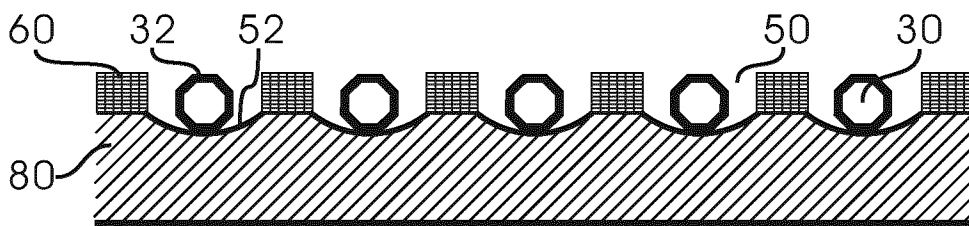


FIG. 7

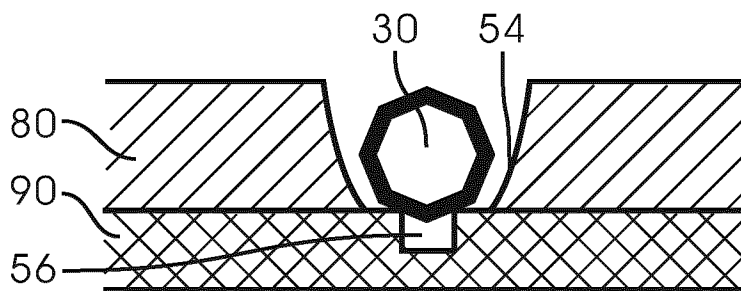


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/050173

<p>A. CLASSIFICATION OF SUBJECT MATTER IPC: B24D 3/00 (2006.01) , B24D 18/00 (2006.01) , B24D 5/06 (2006.01) , B24D 7/06 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC</p>																						
<p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols) IPC: B24D 3/00, B24D 18/00, B24D 5/06 , B24D 7/06</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p> <p>Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Total Patent (major text); Epoque (epodoc); Canadian Patent Database Keywords: (position or orientation), (grain or particle), (plating or deposition), metal coating</p>																						
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>JP2010052070A (Tani, H et al.) 11 March 2010 (11-03-2010) *English Abstract, Figures*</td> <td>1-2, 6-15, 17-24, 28-30,44-51,53, 61-65</td> </tr> <tr> <td>X Y</td> <td>JP2007203443A (Yuichi, S et al.) 16 August 2007 (16-08-2007) *English Abstract, Figures*</td> <td>1-2, 19-20 3-5</td> </tr> <tr> <td>X</td> <td>US2073678 (Broughton, W) 16 March 1937 (16-03-1937) *Figures; pg. 1, col. 2, lines 12-55*</td> <td>1-2,7-11, 15, 17-22, 28-30, 44-47, 53</td> </tr> <tr> <td>Y</td> <td>EP2075092A2 (Kasashima, M et al.) 01 July 2009 (01-07-2009) *Abstract; paragraph 50*</td> <td>1-2, 6-55, 57-73</td> </tr> <tr> <td>Y</td> <td>WO2005/039828 A1 (Hall, R et al.) 6 May 2005 (6-05-2005) *Abstract; pg. 16-18*</td> <td>1-2, 6-73</td> </tr> <tr> <td>Y</td> <td>WO01/26862 A1 (Myoung, B et al.) 19 April 2001 (19-04-2001) *Abstract; Fig. 10A-10B*</td> <td>3-5</td> </tr> </tbody> </table>		Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	JP2010052070A (Tani, H et al.) 11 March 2010 (11-03-2010) *English Abstract, Figures*	1-2, 6-15, 17-24, 28-30,44-51,53, 61-65	X Y	JP2007203443A (Yuichi, S et al.) 16 August 2007 (16-08-2007) *English Abstract, Figures*	1-2, 19-20 3-5	X	US2073678 (Broughton, W) 16 March 1937 (16-03-1937) *Figures; pg. 1, col. 2, lines 12-55*	1-2,7-11, 15, 17-22, 28-30, 44-47, 53	Y	EP2075092A2 (Kasashima, M et al.) 01 July 2009 (01-07-2009) *Abstract; paragraph 50*	1-2, 6-55, 57-73	Y	WO2005/039828 A1 (Hall, R et al.) 6 May 2005 (6-05-2005) *Abstract; pg. 16-18*	1-2, 6-73	Y	WO01/26862 A1 (Myoung, B et al.) 19 April 2001 (19-04-2001) *Abstract; Fig. 10A-10B*	3-5
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Y	WO01/26862 A1 (Myoung, B et al.) 19 April 2001 (19-04-2001) *Abstract; Fig. 10A-10B*	3-5																				
<p><input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.</p> <table border="1"> <tbody> <tr> <td>* Special categories of cited documents :</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td></td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </tbody> </table>		* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family	"O" document referring to an oral disclosure, use, exhibition or other means		"P" document published prior to the international filing date but later than the priority date claimed										
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"P" document published prior to the international filing date but later than the priority date claimed																						
Date of the actual completion of the international search 10 May 2013 (10.05.2013)	Date of mailing of the international search report 23 May 2013 (23-05-2013)																					
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Authorized officer Sean Wilkinson (819) 934-9086																					

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/050173

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP139258 B1 (Kajiyama et al.) 21 January 1987 (21-01-1987) *Abstract; Col. 5, line 29- Col. 6, line 40*	19,56
A	US2007/0151554 A1 (Song, M et al.) 05 July 2007 (05-07-2007) *Abstract; Fig. 10-13*	1-73
A	US2002/0197947 A1 (Sagawa, M) 26 December 2002 (26-12-2002) *Abstract; Fig. 1-5; paragraphs 61-62*	1-73
A	US2003/0084894 A1 (Sung, C) 8 May 2003 (8-5-2003) *Abstract*	1-73

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2013/050173

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
JP2010052070A	11 March 2010 (11-03-2010)	JP4852078B2	11-January 2012
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