The evacuation properties of an abrasive disk are improved by forming its apertures to exhibit a configuration that will direct process fluids onto or away from a workpiece (or contact) interface through capillary action, surface tension/affinity, and/or boundary layer pump actions. The capillary action is accomplished by modifying the geometries of the apertures to form capillary tubes, where the orientation and lift angle of the capillary tubes is controlled to improve the flow of relatively thin layers of liquids. The surface tension/affinity between a liquid material and the abrasive disk is controlled by modifying the through-hole apertures to exhibit a serrated inner surface, which will decrease the attraction between the material of the abrasive disk and the process liquid. A plurality of apertured disks may be stacked, and their respective apertures properly arranged on each surface, to create a Tesla pump such that the kinetic energy associated with rotation of the disk assembly will preferentially bias both the vertical and tangential flow of liquids between the working surface and the disk assembly.
APERTURED ABRASIVE DISK ASSEMBLY WITH IMPROVED FLOW DYNAMICS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/218,473, filed Jun. 19, 2009, which is herein incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates to an abrasive disk assembly and, more particularly, to an abrasive disk assembly including through-hole apertures of a form that create flow of liquid materials between the abrasive disk and the surface being worked, with the configuration of the individual apertures and their arrangement designed to bias the flow of material either away from (i.e., exhaust) or onto (i.e., dispense) the surface being worked (or a combination of both).

BACKGROUND OF THE INVENTION

[0003] When performing any type of grinding or polishing operation, a large amount of abraded material is generally created and needs to be captured and removed from the work area. Additionally, the mechanical abrasion process generates significant heat as a by-product of the frictional forces and plastic deformation of the workpiece; it is advantageous to control this heat with lubricants and/or coolants. Abrasive grinders come in many forms, stationary or portable, where an exemplary form of the prior art comprises a portable body that is adapted to be held by a user, the grinder including a motor that drives an abrasive disk assembly or backing plate, which in turn carries an abrasive disk for grinding the surface of a workpiece. In a “vacuum” type grinder, a shroud in the vicinity of the backing plate and abrasive disk defines a chamber through which air and entrained particles are drawn to an outlet, “powered” by a separate vacuum source, leading to an accumulation point. The abrasive disk and backing plate are provided with holes that, when aligned, form an air passage to allow the flow of air and entrained particles which were drawn by suction to the shroud. At times, liquids are dispensed onto the surface of the article being abraded for cooling and/or to assist in the removal of the surface material and provide a mechanism for transporting the abraded particles away from the workpiece.

[0004] In some abrasive tool configurations, dust is collected in a complex collection system through a hose connected to the abrasive tool. Dust collection systems, however, are not always available for the abrasive tool operator and cannot be used to contain processing liquids that may be need to be extracted from the surface of a work piece.

SUMMARY OF THE INVENTION

[0005] The needs remaining in the prior art are addressed by the present invention, which relates to an abrasive disk assembly utilized in grinding/polishing/planarizing applications and, more particularly, to an abrasive disk assembly including through-hole apertures of a form that create a flow of gaseous and/or liquid materials between an apertured abrasive disk and the surface being worked, with the configuration of the individual apertures and their arrangement designed to bias the flow of liquids either away from (exhaust) or onto (dispense) the surface being worked (or a combination of both).

[0006] In accordance with the present invention, the evacuation properties of an abrasive disk are improved by forming the apertures to exhibit a configuration that will draw process fluids upward through capillary action, surface tension/affinity, and/or boundary layer pump actions. The capillary action of one embodiment of the inventive disk is accomplished by modifying the geometries of the through-hole apertures to form capillary tubes, where the orientation, lift angle and capacity/volume of the capillary tube apertures is controlled to improve the flow (based on the requirements of the process) of relatively thin layers of liquids, to larger volumes of air or coolants; the capillary “tubes” (or spaces) may vary in geometry across the surface of the abrasive disk and can, in fact, include a first set of capillary tubes oriented to bias the flow of liquids toward a working surface and a second set of capillary tubes oppositely oriented to bias the flow of liquids away from a working surface. The surface tension/affinity between a liquid material and the abrasive disk can also be controlled in accordance with the present invention by further modifying the through-hole apertures to exhibit a serrated inner surface, which will decrease the attraction between the material of the abrasive disk and the process liquid. Additionally, a plurality of apertured disks may be stacked, and their respective apertures properly arranged on each surface, to create a Tesla (boundary layer) pump such that the kinetic energy associated with rotation of the disk assembly will preferentially bias both the vertical and tangential flow of liquids between the working surface and the disk assembly, controlling the flows and self-powering the input/dispense and exhaust functions.

[0007] In one embodiment of the present invention, an abrasive disk with improved capillary action is provided by including a plurality of teardrop-shaped apertures across the surface of the abrasive disk, where the wetting angle of the involved materials (i.e., abrasive disk and process fluid) is controlled to provide the desired capillary action. The apertures thus form a plurality of capillary tubes; the tubes themselves may be disposed at an angle with respect to the top and bottom major surfaces of the abrasive disk. The specific geometry of the teardrops can also be modified as a function of placement across the disk (i.e., radial differential) to adjust for differences in fluid movement at the periphery of the disk when compared to the central area of the disk. The orientations of different groupings of the apertures may also be controlled so that a first set of apertures draw liquid away from the working surface, and a second set of apertures direct liquid toward the working surface.

[0008] In an alternative embodiment, the abrasive disk apertures may also be formed to exhibit serrated sidewalls that function to break the surface tension between the process fluid and the material forming the aperture disk itself, thus improving the flow of liquid through the apertures.

[0009] In yet another embodiment of the present invention, a plurality of apertured disks are stacked such that a combination of their apertures form flow paths (input and/or exhaust) that take advantage of the rotational velocity of the stack in the form of a Tesla pump, regulating and controlling the flow volumes associated with the cooling/lubricating (input) and abrading (removal/exhaust) processes.

[0010] Various other aspects and embodiments of the present invention will become apparent during the course of the following discussion and by reference to the accompanying drawings.
BRIEF DESCRIPTION OF THE DRAWINGS
[0011] Referring now to the drawings, where like numerals represent like parts in several views:
[0012] FIG. 1 is a top view of an exemplary apertured abrasive disk formed in accordance with the present invention to encourage capillary flow through the apertures;
[0013] FIG. 2 is a top view of an exemplary teardrop-shaped aperture as included in the apertured conditioning disk of FIG. 1;
[0014] FIG. 3 is a cut-away side view of the teardrop-shaped aperture of FIG. 2;
[0015] FIG. 4 is a cut-away side view of an angularly-disposed, teardrop-shaped aperture for use in the abrasive disk of the present invention;
[0016] FIG. 5 is a top view of an exemplary abrasive disk including capillary action-based apertures having different geometries, formed in accordance with the present invention;
[0017] FIG. 6 is a top view of yet another embodiment of a capillary action-based embodiment of the present invention, with the orientation of the apertures controlled to provide paths for both dispensing liquids to and exhausting liquids from a workpiece surface;
[0018] FIG. 7 is a top view of an alternative aperture geometry for use in the apertured abrasive disk of the present invention, in this case comprising a serrated geometry, used to break the surface tension between the material of the abrasive disk and the composition of the liquid;
[0019] FIG. 8 is a cut-away side view of the serrated aperture of FIG. 7;
[0020] FIG. 9 is an isometric view of the serrated aperture of FIG. 7; and
[0021] FIG. 10 is a cut-away side view of an exemplary Tesla pump configuration of an apertured abrasive disk assembly formed in accordance with the present invention.

DETAILED DESCRIPTION
[0022] In accordance with the present invention, it has been discovered that fluid movement in association with an ablating process can be improved by configuring an abrasive disk assembly to include apertures in the disk that bias the flow of liquids between the disk assembly and working surface. In particular, a plurality of three-dimensional (vertical and horizontal) apertures are formed through the thickness of an abrasive disk to improve flow dynamics in at least one of several ways: (1) configuring the apertures as capillary tubes (e.g., teardrop shape, triangular, diamond, or the like); (2) configuring the apertures to break the surface tension between the disk and the flowing liquid (e.g., serrated apertures, reverse sloped/chamfered walls, etc.); or (3) configuring the disk assembly as a stack of apertured disks to create fluid movement upon rotation (e.g., Tesla pump) and extend the flow toward the periphery.
[0023] By properly designing the apertures of an abrasive disk, for example in a teardrop geometry, it is possible to take advantage of capillary action along a sidewall of the apertures within the abrasive disk to draw the process fluids up and away from a surface being abraded (i.e., an embodiment for exhausting the fluid flow away from the interface between the abrasive disk and the work surface). In essence, each aperture becomes a capillary tube, drawing process fluids up and away from the surface being abraded. Alternatively, the capillary-based apertures may be oriented to encourage the movement of the fluid toward the surface being worked (i.e., an embodiment to bias the flow of liquids toward the interface between the abrasive disk and the work surface), an embodiment useful in dispensing process fluids/coolant onto the work surface.
[0024] FIG. 1 is a top view of an exemplary abrasive disk 10 with improved capillary action formed in accordance with the present invention. In this particular embodiment, abrasive disk 10 is formed to include a plurality of through-hole apertures 12 of a teardrop-shaped geometry that allows for capillary action to take place as shown. While the "teardrop" shape is shown in FIG. 1 and various other drawings, it is to be understood that other geometries, as mentioned above, may also be used. FIG. 2 is an enlarged top view of an exemplary teardrop-shaped abrasive disk aperture 12 and FIG. 3 is an isometric view of an exemplary aperture 12, showing its capillary tube structure. Apertures 12 are understood to be formed through the entire thickness of abrasive disk 10, between its top surface 14 and bottom surface 16. The location of top surface 14 is shown in both FIGS. 1 and 3, with the location of bottom surface 16 indicated in FIG. 3.
[0025] Capillary action is associated with the movement of liquids within thin tubes (or porous material) in an "up-hill" manner contrary to the force of gravity. Capillary action is based on the wetting angle $\alpha$ of the materials involved, in this case, the chemistry of the particular process fluids and the composition of the abrasive disk. For example, when drawing water into a plastic capillary tube (with a surface tension of about 70 mN/m at room temperature), a wetting angle $\alpha$ of 80° has been found sufficient. For purposes of the present invention, an internal angle $\Phi$ of aperture 12 of less than 2*(90°-\alpha) will provide the desired capillary action. FIG. 2 illustrates this internal angle $\Phi$. Presuming a contact angle $\Phi$ of 80°, an internal angle $\Phi$ of 20° or less for aperture 12 is preferred.
[0026] As best shown in FIG. 3, capillary action will draw the process fluids up a sidewall 18 of aperture 12 in the area of internal angle $\Phi$, taking advantage of the surface tension between the fluid and the abrasive disk to initiate/leverage the forces for liquid removal. The capillary action creates an affinity between the process fluids and the material forming the abrasive disk, enhanced by aperture geometry, drawing the fluid up into the capillary tube and away from the surface (when employed in an embodiment where the desired action is to draw the processing fluids and entrained wastes away from the interface). Further improvements in capillary action can be achieved by angling the capillary tube apertures 12 in the manner shown in FIG. 4. In particular, FIG. 4 illustrates an exemplary aperture 12 that has been formed to exhibit an angle $\gamma$ with respect to bottom surface 16 of disk 12.
[0027] By configuring the apertures of the abrasive disk so as to bias the operation of the disk to encourage evacuation of process fluids and wastes, the arrangement of the present invention is able to remove desired amounts from extremely thin layers of liquid (e.g., thickness on the order of 10 $\mu$m), up to large interfacial or air/fluid volumes. Prior abrasive processes have not necessarily been able to take full advantage of the available surface tension for removing such thin layers of material. These apertures can also be designed whereby they are "activated" with adjustments to liquid properties (e.g., surfactants or non-reactive liquids with high or low surface tensions can be added to increase or decrease the contact angle).
[0028] As mentioned above, the capillary action-based apertures in the inventive abrasive disk may comprise different geometries across the surface of the disk. In particular, the capillary action-based apertures around the outer periphery of
the abrasive disk may have a different configuration than the capillary action-based apertures in the central area of the abrasive disk to adjust for rotationally-induced flow dynamics.

[0029] FIG. 5 is a top view of an exemplary abrasive disk 20 including capillary action-based apertures having different geometries in terms of their internal angle (based upon, for example, differences in desired wetting angle as a function of aperture distribution across the disk). Referring to FIG. 5, a first group of apertures 22, formed around the periphery area 24 of disk 20, is configured to exhibit a relatively large internal angle $\phi_{\text{large}}$ while a second group of apertures 26, formed in the central region of disk 20, is configured to exhibit a relatively small internal angle $\phi_{\text{small}}$. The dimensions of the capillary-based apertures may also be modified and multiple other groups of apertures may be included, with each having a specifically-tailored geometry based on, for example, their radial displacement across the surface of the abrasive disk.

[0030] The apertured abrasive disk of the present invention, as noted above, may be used to either effectively dispense liquids onto a surface being worked, or draw liquid away from the surface. It is further possible to configure and arrange capillary action-based apertures that perform both operations (i.e., dispense and exhaust) across the surface of a single disk. FIG. 6 is a top view of one exemplary configuration of this embodiment, with a first plurality of apertures 30 disposed to have the teardrop internal angle $\phi$ disposed on the “left-hand” termination of apertures 30. A second plurality of apertures 32, of similar dimension, are disposed to have their teardrop internal angle disposed on the “right-hand” termination of apertures 32. Upon use, when the disk is rotating in one direction (for example, clockwise), apertures 30 will function to draw liquid upwards and away from a surface being worked (not shown). Alternatively, when the disk is rotating in the opposite direction (for example, counterclockwise), apertures 32 will function to quickly and efficiently dispense liquids onto the surface being worked. As with the arrangement discussed above in FIG. 5, the apertures themselves do not all have to be the same size. Moreover, various ones (or all) of the apertures may further include a serrated interior surface to break the affinity between the disk and the liquid being moved.

[0031] Using apertures of differing geometries will enable balanced evacuation to take place across the surface of the abrasive disk. Additionally, the use of capillary action-based apertures helps to maintain the directional bias during operational conditions such as low rotational speed of the abrasive disk, low effluent flow, and the like. Moreover, as described above, the capillary action-based apertures may be configured to provide embodiments to either draw liquid away from the working surface or dispense liquid onto the working surface, as desired.

[0032] Another technique for improving flow through an apertured disk, as mentioned above, is the use of serrated apertures. FIG. 7 is a top view of an exemplary serrated aperture 50, having corrugated periphery 52 that functions to break the surface tension between the material forming the abrasive disk itself and the liquid flowing through the aperture. FIG. 8 is a cut-away side view of serrated aperture 50, particularly illustrating a set of sidewall fins 54 created by the serrated structure. FIG. 9 is an isometric view of aperture 50. The serrated geometry reduces the liquid/solid surface energy and, as a result, reduces the attraction between the two sufficient to enable the complete transfer of liquid therebetween.

[0033] As mentioned above, the flow of liquids through an abrasive disk assembly may also be improved by using a plurality of stacked disks, with the apertures aligned to assist in the vertical and tangential movement of fluids. FIG. 10 is a cut-away side view of an exemplary disk assembly 60 illustrating this embodiment, which includes an apertured abrasive disk 62 positioned at the “bottom” of the stack and used to perform the abrading action. Abrasive disk 62 includes a plurality of apertures 64, as shown. Also included in disk assembly 60 is a set of backing disks 66, 68 and 70, with apertures 67 formed in disk 66 and apertures 69 formed in disk 68 70. The apertures are shown as being aligned, thus allowing for the free flow of liquids through the stack away from (or on to) the surface being worked. By virtue of having a gap “g” in the spacing between adjacent disks, a plurality of channels (i.e., boundaries) are formed to create a laminar flow situation, efficiently moving liquids away from the worked surface.

[0034] This structure is considered as a Tesla pump arrangement where, as the abrasive disk assembly is rotated, the kinetic energy associated with rotation and surface tension of the liquid causes the liquid to be drawn upward and into the channels, extracting the liquid away from the surface being abraded. The Tesla pump configuration is particularly useful in applications where the disk is rotating at relatively low speeds and an efficient method of removing/dispensing liquid material is desired.

[0035] Having thus described various embodiments of the present invention, it is to be appreciated that there are many other variations, alterations, modifications and improvements of the specifically-described embodiments, as well as their application to other abrasive tool forms (e.g., cup, periphery, shaped, polishing pads, brushes, and the like) that may be made by those skilled in the art. Such variations, alterations, modifications and improvements are intended to be part of this disclosure and thus also intended to be part of this invention. Accordingly, the foregoing description and drawings are by way of the example only, and the scope of this invention is rather defined by the claims appended hereto.

What is claimed is:

1. An abrasive disk assembly comprising:
   a substrate having a top surface and a bottom surface, at least the bottom surface having a coating of an abrasive composition; and
   a plurality of apertures formed through the thickness of the substrate wherein the plurality of apertures are configured to bias the flow of process fluids therethrough.

2. An abrasive disk assembly as defined in claim 1 wherein the plurality of apertures are configured as capillary tubes to bias the flow of liquids therethrough.

3. An abrasive disk assembly as defined in claim 2 wherein the plurality of capillary tube apertures comprise essentially identical dimensions and orientation.

4. An abrasive disk assembly as defined in claim 2 wherein at least a first group of the capillary tube apertures are oriented to direct fluid away from a surface being worked and a second group of the capillary tube apertures are oriented to direct fluid toward a surface being worked.

5. An abrasive disk assembly as defined in claim 2 wherein the plurality of capillary tube apertures comprise a tear-drop-shaped configuration.
6. An abrasive disk assembly as defined in claim 5 wherein each teardrop-shaped aperture is defined by an internal angle \( \phi \) that is defined by the relation \( 2(90^\circ - \alpha) \), where \( \alpha \) is defined as the wetting angle of the fluid passing through the aperture.

7. An abrasive disk assembly as defined in claim 2 wherein the plurality of capillary tube apertures comprise apertures of varying dimension.

8. An abrasive disk assembly as defined in claim 2 wherein the plurality of capillary tube apertures are disposed at a predetermined angle with respect to the thickness of the substrate.

9. An abrasive disk assembly as defined in claim 1 wherein the plurality of apertures comprise a serrated interior wall to reduce the affinity between the material forming the substrate and the liquid passing therethrough.

10. An abrasive disk assembly as defined in claim 1 wherein the assembly further comprises a plurality of apertured disks aligned with the substrate in a stacked configuration so as to create boundary layers therebetween, wherein upon rotation of the abrasive disk assembly the combination of the apertures and boundary layers create laminar flow of liquids between the assembly and a worked surface.

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