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(54) Title: COATED ABRASIVE ARTICLE BASED ON A SUNFLOWER PATTERN

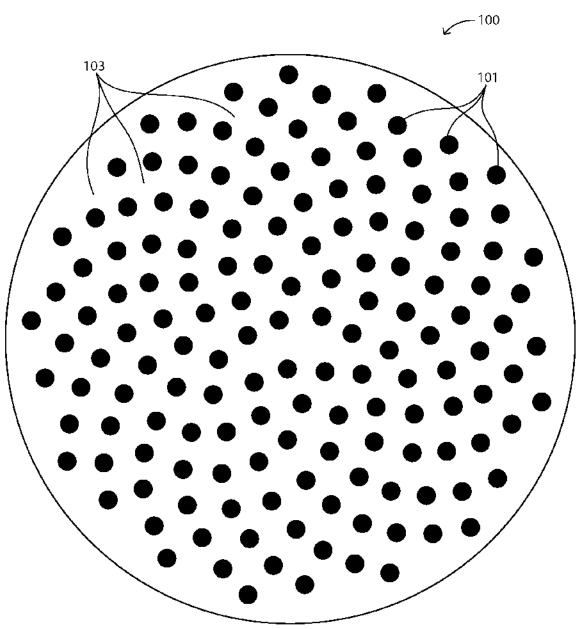

FIG. 1

(57) Abstract: An abrasive article having a plurality of abrasive areas arranged in a non-uniform distribution pattern, wherein the pattern is spiral or phyllotactic, such as a spiral lattice, and in particular those patterns described by the Vogel model, such as a sunflower pattern.

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COATED ABRASIVE ARTICLE BASED ON A SUNFLOWER PATTERN

TECHNICAL FIELD

The present disclosure relates generally to abrasives, and more particularly to coated abrasive articles, having abrasive portions, whether discrete, continuous, semi-continuous, and combinations thereof that are based on the pattern of a sunflower.

BACKGROUND ART

Abrasive articles, such as coated abrasive articles, are used in various industries to abrade work pieces by hand or by machine processes, such as by lapping, grinding, or polishing. Machining utilizing abrasive articles spans a wide industrial and consumer scope from optics industries, automotive paint repair industries, and metal fabrication industries to construction and carpentry. Machining, such as by hand or with use of commonly available tools such as orbital polishers (both random and fixed axis), and belt and vibratory sanders, is also commonly done by consumers in household applications. In each of these examples, abrasives are used to remove surface material and affect the surface characteristics (e.g., planarity, surface roughness, gloss) of the abraded surface. Additionally, various types of automated processing systems have been developed to abrasively process articles of various compositions and configurations.

Surface characteristics include, among others, shine, texture, gloss, surface roughness, and uniformity. In particular, surface characteristics, such as roughness and gloss, are measured to determine quality. For example, when coating or painting a surface certain imperfections or surface defects may occur during the application or curing process. Such surface imperfections or surface defects might include pock marks, “orange peel” texture, “fish eyes”, or encapsulated bubble and dust defects. Typically, such defects in a painted surface are removed by first sanding with a coarse grain abrasive, followed by subsequently sanding with progressively finer grain abrasives, and even buffing with wool or foam pads until a desired smoothness is achieved. Hence, the properties of the abrasive article used will generally influence the surface quality.

In addition to surface characteristics, industries are sensitive to cost related to abrasive operations. Factors influencing operational costs include the speed at which a surface can be prepared and the cost of the materials used to prepare that surface. Typically, the industry seeks cost effective materials having high material removal rates.

However, abrasives that exhibit high removal rates often exhibit poor performance in achieving desirable surface characteristics. Conversely, abrasives that produce desirable surface characteristics often have low material removal rates. For this reason, preparation of a surface is often a multi-step process using various grades of abrasive sheets. Typically, surface flaws (e.g., scratches) introduced by one step are repaired (e.g., removed) using progressively finer grain abrasives in one or more subsequent steps. Therefore, abrasives that introduce scratches and surface flaws result in increased time, effort, and expenditure of materials in subsequent processing steps and an overall increase in total processing costs.

An additional factor affecting material removal rate and surface quality is the “loading” of the abrasive with “swarf”, i.e., the material that is abraded from the workpiece surface, which tends to accumulate on the surface of, and between, the abrasive particles. Loading is undesirable because it typically reduces the effectiveness of the abrasive product and can also negatively affect surface characteristics by increasing the likelihood of scratching defects.

Although various efforts have been made to reduce the accumulation of swarf, such as the introduction of fluids onto the workpiece surface to wash away swarf, as well as the application of vacuum systems to carry away swarf as it is generated, there continues to be a demand for improved, cost effective, abrasive articles, processes, and systems that promote efficient abrasion and improved surface characteristics.

BRIEF DESCRIPTION OF DRAWINGS

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

FIG. 1 is an embodiment of a coated abrasive disc without any apertures and having a pattern with a controlled non-uniform distribution of abrasive areas (a.k.a., spots) according to the present invention.

FIG. 2 is an illustration of an embodiment of a coated abrasive having abrasive areas in the form of multiple spiral arms, the spiral arms passing through points conforming to the Vogel model.

FIG. 3 is an illustration of an embodiment of a coated abrasive disc without any apertures and having abrasive areas corresponding to a phyllotactic spiral pattern, specifically a type of spiral lattice, having clockwise and counterclockwise parastichy according to the present invention.

FIG. 4 is another illustration of an embodiment of a coated abrasive disc without any apertures having abrasive areas in the form of a phyllotactic spiral pattern of clockwise and counterclockwise parastichy according to the present invention.

FIG. 5 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern, specifically a type of spiral lattice, having clockwise and counterclockwise parastichy in combination with circular abrasive areas where the parastichy intersect according to the present invention.

FIG. 6 is an illustration of the Vogel model for placement of abrasive areas in accordance with the present invention.

FIG. 7 is another illustration of the Vogel model in accordance with the present invention showing a numerical progression of the placement of the abrasive areas.

FIG. 8A - 8C are illustrations of phyllotactic spiral patterns for the placement of abrasive areas on a coated abrasive, the patterns conforming to the Vogel model and that have differing divergence angles according to the present invention.

FIG. 9 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern, specifically a type of spiral lattice, having clockwise and counterclockwise parastichy in combination with circular abrasive areas of varying size where the parastichy intersect according to the present invention.

FIG. 10 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern having branched parastichy in combination with circular abrasive areas of varying size where the parastichy branch according to the present invention.

FIG. 11 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern having branched clock-wise parastichy in combination with circular abrasive areas of varying size where the parastichy branch according to the present invention.

FIG. 12 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern having branched clock-wise and counter clock-wise parastichy in combination with circular abrasive areas of varying size where the parastichy branch according to the present invention.

FIG. 13 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern having branched parastichy in combination with circular abrasive areas of varying size where the parastichy branch according to the present invention.

FIG. 14 is an illustration of another embodiment of a coated abrasive disc having abrasive areas corresponding to a phyllotactic spiral pattern having branched parastichy in combination with circular abrasive areas of varying size where the parastichy branch according to the present invention.

FIG. 15 is a graphical image of an embodiment of an abrasive area pattern having 148 abrasive areas according to the present invention

FIG. 16 is an illustration of an embodiment according to the present invention of an alternate abrasive pattern that is a transpose of abrasive pattern of FIG. 15

FIG. 17 is an illustration of an embodiment of abrasive areas in the form of spirals and arcs based on the pattern of FIG. 16

FIG. 18 is a graphical image of an exemplary embodiment of an abrasive area pattern having 344 abrasive areas according to the present invention

FIG. 19 is an illustration of an exemplary embodiment according to the present invention of a transpose of the abrasive area pattern of FIG. 18

FIG. 20 is an illustration of an exemplary embodiment according to the present invention of a back-up pad that is co-operative with the aperture pattern of FIG. 19

FIG. 21 is a cross-sectional view of an embodiment of a coated abrasive according to the present invention.

The use of the same reference symbols in different drawings indicates similar or identical items.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In an embodiment, an abrasive article comprises a coated abrasive having a plurality of abrasive areas arranged in a pattern having a controlled non-uniform distribution. The pattern can be any pattern having a controlled non-uniform distribution, including a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof. An example of a combination pattern is a spiral lattice pattern. The pattern can be partially, substantially, or fully asymmetric. The pattern can cover (i.e., be distributed over) the entire abrasive article, can cover substantially the entire abrasive article (i.e. greater than 50% but less than 100%), can cover multiple portions of the abrasive article, or can cover only a portion of the abrasive article.

A controlled "non-uniform distribution" means that the pattern has a controlled asymmetry (i.e., a controlled randomness), such that although the distribution of abrasive areas can be described by or predicted by, for example, a radial, spiral, or phyllotactic equation, the pattern still exhibits at least a partial to complete asymmetry.

The controlled asymmetry can be a controlled reflection asymmetry (also called mirror symmetry, line symmetry, and bilateral symmetry), a controlled rotational asymmetry, a controlled translational symmetry, controlled glide reflection symmetry, or combinations of thereof. An example of a non-uniform distribution can be demonstrated for a radial, spiral, or phyllotactic pattern having a rotational symmetry of an order of one, meaning that such a pattern has no rotational symmetry because the pattern repeats itself only once during a rotation of 360° about its center. In other words, if two copies of the same exact pattern are placed directly over each other and one copy is held constant while the second copy is rotated 360° about its center, all of the abrasive areas of both copies will come into alignment only once during the 360° rotation.

Typically, all abrasive areas of a pattern (i.e., the entire pattern) will possess a controlled asymmetry. However, it is contemplated that patterns according to the present embodiments also include patterns where only a portion of the total number of abrasive areas of the pattern (i.e., a portion of the pattern) possesses a controlled asymmetry. Such can occur for instance by combining, or substituting, a portion of a uniformly distributed pattern, or a completely random pattern, with a pattern having controlled a controlled non-uniform distribution such that only a portion of the abrasive areas of the resulting pattern have a controlled non-uniform distribution. The portion of the total abrasive areas that have a controlled non-uniform can be quantified as a discrete number, or as a fraction, percentage, or ratio of the total number of abrasive areas of the pattern. In an embodiment, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 80%, at least 85%, at least

90%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, at least 99.5%, at least 99.9% of the abrasive areas of the pattern possess a controlled asymmetry. The portion of abrasive areas of the pattern possessing a controlled asymmetry can be within a range comprising any pair of the previous upper and lower limits. In a particular embodiment, from about 50% to about 99.9%, from about 60% to about 99.5%, from about 75% to about 99%% of the pattern possesses a controlled non-uniform distribution.

In another embodiment, the pattern possesses controlled asymmetry over at least approximately 5 abrasive areas, at least approximately 10 abrasive areas, at least approximately 15 abrasive areas, at least approximately 20 abrasive areas, at least approximately 25 abrasive areas, or at least approximately 50 abrasive areas. In another embodiment, the pattern possesses controlled asymmetry over not greater than approximately 100,000 abrasive areas, not greater than approximately 10,000 abrasive areas, not greater than approximately 5,000 abrasive areas, not greater than approximately 2,500 abrasive areas, not greater than approximately 1,000 abrasive areas, not greater than approximately 750 abrasive areas, or not greater than approximately 500 abrasive areas. The number of abrasive areas possessing controlled asymmetry can be within a range comprising any pair of the previous upper and lower limits.

As stated above, a pattern of the present embodiments can be any pattern having a controlled non-uniform distribution, including a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof. An example of a combination pattern is a spiral lattice pattern. It will be recognized that a spiral lattice pattern can be classified as a can be a radial pattern, a spiral pattern, a phyllotactic pattern, and an asymmetric pattern. A radial pattern can be any pattern that appears to radiate from a central point, such as spokes from the hub of a wheel.

In an embodiment, a spiral pattern can be any curve, or set of curves, that emanates from a central point on the abrasive article and extends progressively farther away as it revolves around the central point. The central point can be located at or near the center of the abrasive article, or alternatively, away from the center of the abrasive article. There can be a single spiral or multiple spirals (i.e., a plurality of spirals). The spirals can be discreet or continuous, separate or joined. Separate spirals can emanate from different central points (i.e., each spiral has its own central point), can emanate from a common central point (i.e., each spiral shares a central point), or combinations thereof. Spiral patterns can include: an Archimedean spiral; a Euler spiral, Cornu spiral, or clothoid; a Fermat's spiral; a hyperbolic spiral; a lituus; a logarithmic spiral; a Fibonacci spiral; a golden spiral; or combinations thereof.

In an embodiment, the pattern can be a phyllotactic pattern. As used herein, “a phyllotactic pattern” means a pattern related to phyllotaxis. Phyllotaxis is the arrangement of lateral organs such as leaves, flowers, scales, florets, and seeds in many kinds of plants. Many phyllotactic patterns are marked by the naturally occurring phenomenon of conspicuous patterns having arcs, spirals, and whorls. The pattern of seeds in the head of a sunflower is an example of this phenomenon. As shown in FIG. 3 and FIG. 4, multiple arcs or spirals, also called parastichy, can have their origin at a center point (C) and travel outward, while other spirals originate to fill in the gaps left by the inner spirals. See Jean's Phyllotaxis A Systemic Study in Plant Morphogenesis at p. 17. Frequently, the spiral-patterned arrangements can be viewed as radiating outward in both the clockwise and counterclockwise directions. As shown in FIG. 4, these types of patterns have visibly opposed parastichy pairs that can be denoted by (m, n) where the number of spirals or arcs at a distance from the center point radiating in a clockwise direction is “m” and the number of spirals or arcs radiating counterclockwise is “n.” Further, the angle between two consecutive spirals or arcs at their center is called the divergence angle “d.” It has been surprisingly discovered by the inventors that phyllotactic patterns are useful in creating new patterns for abrasive articles, in particular coated abrasive articles.

In an embodiment, the pattern has a number of clockwise spirals and a number of counter-clock wise spirals, wherein the number of clockwise spirals and the number of counterclockwise spirals are Fibonacci numbers or multiples of Fibonacci numbers. In a particular embodiment, the number of clockwise spirals and the number of counterclockwise spirals is, as a pair (m, n): (3, 5), (5, 8), (8, 13), (13, 21), (21, 34), (34, 55), (55, 89), (89, 144) or a multiple of such pairs. In another embodiment, the number of clockwise spirals and the number of counterclockwise spirals are Lucas numbers or multiples of Lucas numbers. In a particular embodiment, the number of clockwise spirals and the number of counterclockwise spirals is, as a pair (m, n): (3, 4), (4, 7), (7, 11), (11, 18), (18, 29), (29, 47), (47, 76), or (76, 123), or a multiple of such pairs. In another embodiment, the number of clockwise spirals and the number of counterclockwise spirals are any numbers in a ratio that converges on the golden ratio, wherein the golden ratio is equal to the sum of one plus the square root of five, divided by two $(1+\sqrt{5})/2$, which is approximately equal to 1.6180339887. In a particular embodiment, the ratio of the clockwise spirals to the counterclockwise spirals is approximately equal to the golden ratio.

As already mentioned above, it has been observed in nature that the seeds of the sunflower plant are arranged in a spiral phyllotactic pattern. In an embodiment, the pattern is a sunflower pattern.

The sunflower pattern has been described by Vogel’s model, which is a type of "Fibonacci spiral", or a spiral in which the divergence angle between successive points is a fixed Fibonacci angle that approaches the golden angle, which is equal to 137.508°.

FIG. 6 and FIG. 7 illustrate the Vogel model, which is:

$$\varphi = n * \alpha, \quad r = c\sqrt{n} \qquad \text{(Eq. 1)}$$

where:

n is the ordering number of a floret, counting outward from the center;

φ is the angle between a reference direction and the position vector of the *nth* floret in a polar coordinate system originating at the center of the capitulum, such that the *divergence angle*, α, between the position vectors of any two successive florets is constant, and with regard to the sunflower pattern, at 137.508°;

r is the distance from the center of the capitulum and the center of the nth floret; and

c is a constant scaling factor.

In an embodiment, the pattern is described by the Vogel model or a variation of the Vogel model. In a particular embodiment, the pattern is described by the Vogel model where:

n is the ordering number of an abrasive area, counting outward from the center of the pattern;

φ is the angle between a reference direction and a position vector of the nth abrasive area in a polar coordinate system originating at the center of the pattern, such that the divergence angle between the position vectors of any two successive abrasive areas is a constant angle α;

r is the distance from the center of the pattern to the center of the nth abrasive area; and c is a constant scaling factor.

As stated above, all, substantially all, or a portion of the abrasive areas of the pattern will be described by (i.e., conform to) the Vogel model. In an embodiment, all the abrasive areas of the pattern are described by the Vogel model. In another embodiment at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, at least 99% of the abrasive areas are described by the Vogel model.

In another embodiment, a suitable spiral or phyllotactic pattern can be generated from the *x* and *y* co-ordinates of any phyllotactic pattern, such as the Vogel model, or other suitable pattern having a controlled non-uniform distribution, including a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof. In an embodiment, the x and y co-ordinates of a spiral or phyllotactic pattern are transposed and rotated to determine the *x'* and *y'* co-ordinates of the spiral or phyllotactic pattern, wherein θ is equal to π/n in radians and n is any integer according to the following equation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad \text{(Eq. 2)}$$

The transposed and rotated co-ordinates produced *(x' and y')* can be plotted, such as by the use of computer aided drafting (CAD) software, to generate a spiral or phyllotactic pattern. Particular embodiments of transposed phyllotactic patterns are shown in FIG. 16, which is a transpose of the phyllotactic pattern of FIG. 15; and FIG. 19, which is a transpose of the phyllotactic pattern of FIG. 18.

The inventors have surprisingly found that phyllotactic patterns are useful in creating new patterns that improve the performance of abrasive articles, including fixed abrasive articles, such as bonded abrasive articles and coated abrasive articles. In particular, phyllotactic patterns are useful in creating new abrasive area patterns for coated abrasive articles. Phyllotactic patterns help solve the competing problems of achieving a high removal rate of surface material while still achieving an acceptable surface quality, reducing the amount of swarf loading on the abrasive surface, and maintaining a high durability and long useful life of the abrasive. This is surprising, in part, in at least the following respects. First, the phyllotactic patterns of the present embodiments unexpectedly provide improved to superior swarf removal coverage and have a more complete intermingled distribution of swarf extraction sites (e.g., open areas, pathways, and/or channels) and abrasive areas (for instance, in the form of individual abrasive spots, elongated nodes, semi-continuous arcs, whorls, spirals, and combinations thereof as described and shown herein) over the face of the abrasive compared to state-of-the-art abrasive patterns, even when having a total abrasive area that is less than the total abrasive area of a state-of-the-art pattern. Second, phyllotactic patterns of the present embodiments unexpectedly provide at least comparable to superior abrasive performance (e.g., cumulative material cut) compared to state-of-the-art patterns, with and without the application of vacuum, even when the total abrasive area is less than that of state-of-the-art patterns. Third, as discussed in more detail later in the application, the effectiveness and performance of the present embodiments can be even further enhanced when paired with a co-operative back-up pad and vacuum system.

It will be appreciated that important aspects of pattern design for coated abrasive articles include the percentage of total abrasive surface area, the ratio of total abrasive surface area to open area, the predicted locations and extensiveness of abrasive area coverage while the abrasive article is in use (e.g., rotational movement in an orbital sander, oscillation movement in a sheet sander, continuous lateral movement in a belt sander), the scaling factor, the number of abrasive areas, the divergence angle between the abrasive areas, the size and shape of the abrasive areas, the distance between adjacent abrasive areas, and the distance between the outermost abrasive areas and the edge, or edges, of the coated abrasive article.

Sizes of abrasive discs

There are various sizes of abrasives that are commonly used in industry and by commercial consumers that typically range from about fractions of an inch in diameter up to feet in diameter. The present patterns are suitable for use on abrasives of most any size, including various standard sizes of abrasive discs (e.g., 3 inch to 20 inch). In an embodiment, the abrasive article is a circular disc having a diameter of at least about 0.25 inches, at least about 0.5 inches, at least about 1.0 inches, at least about 1.5 inches, at least about 2.0 inches, at least about 2.5 inches, or at least about 3.0 inches. In another embodiment, the abrasive article is a circular disc having a diameter of not greater than about 72 inches, not greater than about 60 inches, not greater than about 48 inches, not greater than about 36 inches, not greater than about 24 inches, not greater than about 20 inches, not greater than about 18 inches, not greater than about 12 inches, not greater than about 10 inches, not greater than about 9 inches, not greater than about 8 inches, not greater than about 7 inches, or not greater than about 6 inches. In another embodiment, the abrasive article has a size in the range from about 0.5 inches in diameter to about 48 inches in diameter, about 1.0 inch in diameter to about 20 inches in diameter, about 1.5 inches in diameter to about 12 inches in diameter.

Total Potential Surface Area

The size and shape of the abrasive article determines the total potential surface area of the abrasive article. For instance, an abrasive disc having a 1 inch diameter has a total potential surface area of 0.7854 in^2. As another example, a rectangular abrasive sheet measuring 2 inches by 3 inches would have a total potential surface area of 6 in^2.

Total Open Area

The total open area affects the amount of swarf extraction. Typically, as the amount of open area increases, the amount of swarf extraction increases, which tends to maintain, or sometimes improve the abrasive article's material removal rate (i.e. "cut" rate) during usage. However, increasing the amount of open area also directly reduces the amount of available abrasive area, which at a certain point will reduce the material removal rate. In an embodiment, the total open area is equal to the sum of the area of all the open areas on the face of the abrasive article. In other words, the total open area is equal to the total potential surface of the abrasive article minus the total abrasive area (i.e., the sum of all the abrasive areas). Thus, the amount of the total open area can range from about 15% to about 95.5% of the total potential surface area, depending on the amount of desired abrasive area. In an embodiment, the total open area is at least about 15% of the total potential surface area for the abrasive article, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, or at least about 80%. In another embodiment, the total open area is not greater than about 95.5%, not greater than about 95%, not greater than about 94.5%, not greater than about 94%, not greater than about 93.5%, not greater than about 93%, not greater than about 92.5%, not greater than about 92%, not greater than about 91.5%, not greater than about 91%, not greater than about 90.5%, or not greater than about 90%. The amount of the total open area can be within a range comprising any pair of the previous upper and lower limits. In another embodiment, the total open area ranges from about 65% to about 93%, about 70% to about 92%, about 75% to about 91%, or about 80% to about 90%. The total open area may be considered as a discreet amount instead of a percentage. For example, an abrasive five inch disc can have a total open area ranging from about 2.95 in^2 to about 18.75 in^2.

Total abrasive surface area

The total abrasive surface area affects the amount surface material removed. Typically, as the amount of total abrasive surface area is increased, the amount of surface material removed is increased. Also typically, as the amount of surface material removed is increased, both the tendency for swarf to build-up is increased and the surface roughness tends to increase. In an embodiment, the total abrasive surface area of the coated abrasive is equal to the total potential surface of the abrasive article (i.e., the abrasive surface area if there were no apertures) minus the total open area (i.e., the sum of all the open areas). Thus, the amount of the total abrasive surface area can range from about 4.5% to about 85% of the total potential surface area, depending on the amount of desired open area. In an embodiment, the total abrasive area is at least about 4% of the total potential surface area for the abrasive article, at least about 4.5%, at least about 5%, at least about 5.5%, at least about 6%, at least about 7.5%, at least about 8%, at least about 8.5%, at least about 9%, at least about 9.5%, or at least about 10%. In another embodiment, the total abrasive area is not greater than about 85%, not greater than about 80%, not greater than about 75%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, or not greater than about 20%. The amount of the total abrasive area can be within a range comprising any pair of the previous upper and lower limits. In another embodiment, the total abrasive area ranges from about 7% to about 35%, about 8% to about 30%, about 9% to about 25%, or about 10% to about 20%. The total abrasive area may be considered as a discreet amount instead of a percentage. For example, a 5-inch disc can have a total abrasive surface area ranging from about 0.88 in^2 to about 16.69 in^2.

Ratio of Total Abrasive Surface Area to Total Open Area

In an embodiment, the ratio of total abrasive surface area to total open area is at least about 1:199, at least about 1:99, at least about 1:65.7; at least about 1:49, at least about 1:39, at least about 1:29, at least about 1:19, or at least about 1: 9. In another embodiment, the ratio of total abrasive surface area to total open area is not greater than about 1:0.05, not greater than about 1:0.1, not greater than about 1:0.2, not greater than about 1:0.3, not greater than about 1:0.4, not greater than about 1:0.5, not greater than about 1:0.6, not greater than about 1:0.7, not greater than about 1:0.8, not greater than about 1:0.9, or not greater than about 1:1. The ratio of total abrasive surface area to total open area can be within a range comprising any pair of the previous upper and lower limits.

Number of abrasive areas

The number of abrasive areas influences the total amount of open area and the amount of total abrasive area. Additionally, the number of abrasive areas affects the density and distribution of abrasive coverage on the surface of the abrasive article, which in turn directly affects the surface material removal rate and swarf extraction efficiency of the abrasive article. In an embodiment, the number of abrasive areas is at least about 5, at least about 10, at least about 15; at least about 18, or at least about 21. In another embodiment, the number of abrasive areas is not greater than about 100,000; not greater than about 50,000; not greater than about 10,000; not greater than about 1,000;

not greater than about 800; not greater than about 750; not greater than about 600; or not greater than about 550. The number of abrasive areas can be within a range comprising any pair of the previous upper and lower limits. In another embodiment, the number of abrasive areas ranges from about 21 to about 10,000; about 25 to about 1,000; about 30 to about 750; or about 35 to about 550. In a particular embodiment, the number of abrasive areas is in the range of about 21 to about 550.

Divergence Angle

Increasing or decreasing the divergence angle α affects how the abrasive areas are placed within the pattern and the shape of the clockwise and counter clockwise spirals. The divergence angle is equal to 360° divided by a constant or variable value, thus the divergence angle can be a constant value or it can vary. It has been observed that small changes in divergence angle can significantly alter the pattern. FIG.8a, FIG.8b, and FIG.8c show phyllotactic patterns that differ only in the value of the divergence angle. The divergence angle for FIG.8a is 137.3°. The divergence angle for FIG.8b is 137.5°. The divergence angle for FIG.8c is 137.6°. In an embodiment, the divergence angle is at least about 30°, at least about 45°, at least about 60°; at least about 90°, or at least about 120°. In another embodiment, the divergence angle is less than 180°, such as not greater than about 150°. The divergence angle can be within a range comprising any pair of the previous upper and lower limits. In another embodiment, the divergence angle ranges from about 90° to about 179°, about 120° to about 150°, about 130° to about 140°, or about 135° to about 139°. In an embodiment, the divergence angle is determined by dividing 360° by an irrational number. In a particular embodiment, the divergence angle is determined by dividing 360° by the golden ratio. In a particular embodiment, the divergence angle is in the range of about 137° to about 138°, such as about 137.5° to about 137.6°, such as about 137.50° to about 137.51°. In a particular embodiment, the divergence angle is 137.508°.

Distance to the Edge of the Abrasive

Depending on the geometry of the abrasive article and its intended usage, the overall dimensions of the pattern can be determined. The distance from the center of the pattern to the outermost abrasive areas can extend to a distance coterminous with the edge of the abrasive article. Thus, the edges of the outermost abrasive areas can extend to or intersect with the edge of the abrasive article. Alternatively, the distance from the center of the pattern to the outermost abrasive areas can extend to a distance that allows a certain amount of space between the edges of the outermost abrasive areas and the edge of the abrasive article to be free of abrasive areas. The minimum distance from the edges of the outermost abrasive areas can be specified as desired. In an embodiment, the minimum distance from the edges of the outermost abrasive areas to the outer edge of the abrasive article is a specific distance, identified as a discreet length or as a percentage of the length of the face of the abrasive article upon which the pattern appears. In an embodiment, the minimum distance from the edges of the outermost abrasive areas to the outer edge of the abrasive article can be at least about zero (i.e., the edge of the outermost abrasive areas intersect or are co-terminus with the edge of the abrasive article) ranging to about 15% of the length of the face of the abrasive article.

Size of Abrasive areas

The size of the abrasive areas is determined, at least in part, by the desired total amount of abrasive area for the abrasive article. The size of the abrasive areas can be constant throughout the pattern or it can vary within the pattern. In an embodiment, the size of the abrasive areas is constant. In another embodiment, the size of the abrasive areas varies with the distance of the abrasive areas from the center of the pattern.

Scaling factor

The scaling factor influences the overall size and dimensions of the pattern. The scaling factor can be adjusted so that the edges of the outermost abrasive areas are within a desired distance of the outer edge of the abrasive article.

Distance Between Nearest Adjacent Abrasive areas

Along with consideration of the number and size of the abrasive areas, the distance between the centers of the nearest adjacent abrasive areas can be determined. The distance between the centers of any two abrasive areas is a function of the other design considerations. In an embodiment, the shortest distance between the center of any two abrasive areas is never repeated (i.e., the center-to-center spacing is never the same exact distance). This type of spacing is also an example of controlled asymmetry.

Pattern Coverage - Acceptable Amounts of Anomalies

It will be apparent that a pattern need not be applied to an abrasive article in its entirety or in a continuous manner. Portions of a pattern may be applied or skipped such that various divisions or sectors of the face of the abrasive article do not bear the complete pattern. In an embodiment, a half, a third, a quarter, a fifth, a sixth, a seventh, an eighth, a ninth, or a tenth of the pattern may be skipped. In another embodiment, the pattern may be applied to only one or more concentric annular regions of the abrasive article. In another embodiment, it is possible to skip one or more of the abrasive areas that would normally appear in the series of abrasive areas along the individual arcs or spiral arms of the pattern. In an embodiment, every n^{th}, or multiple of every n^{th} could be skipped. In another embodiment, individual abrasive areas, groups of abrasive areas, or abrasive areas according to a specific numerical series can be skipped. Conversely, it is also possible to include a certain amount of additional abrasive areas to the pattern. The addition or subtraction of abrasive areas can be considered as anomalies to the pattern, and a certain amount of anomalies to the pattern, plus or minus, can be acceptable. In an embodiment, an acceptable amount of anomalies to the pattern can range from 0.1% to 10% of the total abrasive areas of the abrasive article.

Shape of the abrasive areas

The amount of coverage can be influenced by the shape of the abrasive areas. The shape of the abrasive areas can be regular or irregular. In an embodiment, the shape of the abrasive areas can be in the form of short lines, regular polygons, irregular polygons, ellipsoids, circles, arcs, spirals, whorls, lattices, or combinations thereof. In a particular embodiment, the abrasive areas have the shape of a circle. In another embodiment, the shape of the abrasive areas may be in the form of one or more lines, arcs, spirals, or whirls having a controlled non-uniform distribution as described herein. The one or more lines, arcs, spirals, or whirls can have multiple lines intersect.

The abrasive areas can be configured so that sufficient swarf removal can occur with or without the attachment of a vacuum to the back of the abrasive article. In an embodiment, the abrasive areas are in form of spirals or parastichy that extend radially outward from the center of the abrasive article, The spirals or parastichy can be configured to create air-flow channels in the open areas between the abrasive areas. In another embodiment, the abrasive areas are formed to resemble a spiral lattice. Apertures can be located within the open areas enclosed by the lattice. It is believed that swarf removal will be promoted by the presence of open areas that are in fluid connection with the outer edge of the abrasive article, or that are in fluid connection with apertures in the abrasive article that open to a vacuum source, or both. Such abrasive areas and open areas configured to create air-flow paths will guide swarf so that it is ejected out from the abrasive areas by centrifugal force or directly into the apertures of a vacuum system, thus preventing entrainment of the swarf in the abrasive areas on the face of the abrasive article, as well as any open fibrous layers, such as hook and loop material layers, that might be attached to the backside of the abrasive article.

In an embodiment, the pattern of abrasive areas can comprise regular polygons, irregular polygons, ellipsoids, arcs, spirals, phyllotactic patterns, or combinations thereof. The pattern of abrasive areas can comprise radiating arcs, radiating spirals, or combinations thereof. The pattern of abrasive areas can comprise a combination of inner radiating spirals and outer radiating spirals. The pattern of abrasive areas can comprise a combination of clock-wise radiating spirals and counter clock-wise radiating spirals. The abrasive areas can be discrete, or discontinuous, from each other. Alternatively, one or more of the abrasive areas can be fluidly connected.

The number of radiating arcs, radiating spirals, or combinations thereof can vary. In an embodiment, the number of radiating arcs, radiating spirals, or combinations thereof can be not greater than 1000, such as not greater than 750, not greater than 500, not greater than 250, not greater than 100, not greater than 90, not greater than 80, or not greater than 75. In an embodiment, the number of radiating arcs, radiating spirals, or combinations thereof can be not less than 2, such as not less than 3, not less than 5, not less than 7, not less than 9, not less than 11, not less than 15, or not less than 20. In an embodiment, the number of radiating arcs, radiating spirals, or combinations thereof can be from 2 to 500, such as 2 to 100.

The abrasive areas can vary in width. The width of the abrasive areas can be constant or varying, or combinations thereof. In an embodiment, the width of the abrasive areas can be within a range of fixed lengths. In an embodiment, the width of the abrasive areas can vary from 0.1 mm to 10 cm. In another embodiment, the width of the abrasive areas will be related to the desired size of the adjacent open areas of the abrasive article. In an embodiment, the width of the abrasive areas is not less than 1/10 the size of the open areas of the abrasive article, such as not less than 1/8, 1/6, 1/5, 1/4, 1/3, or 1/2 the size of the open areas of the coated abrasive. In an embodiment, the width of the abrasive areas is not greater than 10 times the size of the open areas of the coated abrasive, such as not greater than 8 times, not greater than 6 times, not greater than 5 times, not greater than 4 times, not greater than 3 times, not greater than 2 times the size of the open areas of the coated abrasive. In an embodiment, the width of the abrasive areas is about equal to the size of the open areas of the coated abrasive.

In another embodiment, the abrasive areas can be shaped and configured to form a plurality of air flow paths disposed in a pattern. The pattern of air flow paths can comprise regular polygons, irregular polygons, ellipsoids, arcs, spirals, phyllotactic patterns, or combinations thereof. The pattern of air flow paths can comprise radiating arcurate paths, radiating spiral paths, or combinations thereof. The pattern of air flow paths can comprise a combination of inner radiating spiral paths and outer radiating spiral paths. The pattern of air flow paths can comprise a combination of clock-wise radiating spiral paths and counter clock-wise radiating spiral paths. The air flow paths can be discrete, or discontinuous, from each other. Alternatively, one or more of the air flow paths can be can be fluidly connected.

The number of radiating arcurate paths ("arcs"), radiating spiral paths, or combinations thereof can vary. In an embodiment, the number of radiating arcurate paths, radiating spiral paths, or combinations thereof can be not greater than 1000, such as not greater than 750, not greater than 500, not greater than 250, not greater than 100, not greater than 90, not greater than 80, or not greater than 75. In an embodiment, the number of radiating arcurate paths, radiating spiral paths, or combinations thereof can be not less than 2, such as not less than 3, not less than 5, not less than 7, not less than 9, not less than 11, not less than 15, or not less than 20. In an embodiment, the number of radiating arcurate paths, radiating spiral paths, or combinations thereof can be from 2 to 500, such as 2 to 100.

The air flow paths can vary in width. The width of the air flow paths can be constant or varying, or combinations thereof. In an embodiment, the width of the air flow paths can be within a range of fixed lengths. In an embodiment, the width of the air flow paths can vary from 0.1 mm to 10 cm. In another embodiment, the width of the air flow paths will be related to the size of the abrasive areas of the coated. In an embodiment, the width of the air flow paths is not less than 1/10 the size of the abrasive areas of the coated abrasive, such as not less than 1/8, 1/6, 1/5, 1/4, 1/3, or 1/2 the size of the abrasive areas of the coated abrasive. In an embodiment, the width of the air flow paths is not greater than 10 times the size of the abrasive areas of the coated abrasive, such as not greater than 8 times, not greater than 6 times, not greater than 5 times, not greater than 4 times, not greater than 3 times, not greater than 2 times the size of the abrasive areas of the coated abrasive. In an embodiment, the width of the air-flow paths is about equal to the size of the abrasive areas of the coated abrasive.

The air flow paths can have one or more cavities, orifices, passages, holes, openings, or combinations thereof disposed along or within air flow paths that extend through the through the body of the abrasive article. In an embodiment, each air flow path will have at least one hole disposed within the air flow path that that extends through the through the body of the abrasive article.

Shape and Structure of the Abrasive Article

The shape of the abrasive article can be any shape that will accommodate the desired abrasive area pattern and will be dictated by the intended abrasive process and materials of construction. In an embodiment, the abrasive article is a bonded abrasive article. In another embodiment, the abrasive article is a coated abrasive article. In a particular embodiment, the abrasive article is one of a sheet, belt, or circular disc.

FIG. 1 shows a top view of an embodiment of a coated abrasive article 100 having a plurality of abrasive areas 101 arranged in a pattern having a non-uniform distribution, wherein the pattern is a phyllotactic spiral pattern that conforms to the Vogel model (commonly called a “sunflower” pattern). Open areas 103 surround the abrasive areas. The coated abrasive is in the shape of a substantially planar (i.e., generally flat) circular disc.

FIG. 21 shows a side view of a coated abrasive article 2100 including a backing 2101 having a first major surface 2103 and a second major surface 2105. An abrasive layer 2107 is disposed on the first major surface of the backing. The abrasive layer can comprise multiple layers, including a binder layer 2109, also called a make coat. A plurality of abrasive grains 2111 can be dispersed within, penetrating into, or resting upon the binder layer, or combinations thereof. A pattern of abrasive areas 2113 are present on the surface of the backing. One or more open areas 2115 will be adjacent to the abrasive areas. A size coat 2117 can optionally be disposed on the binder layer. A supersize coat 2119 can optionally be disposed over the size coat. A back coat 2121 can be disposed on the second major surface (i.e., the non-abrasive side) of the backing layer. A fastener layer 2123 can be disposed over the back coat, or alternatively can be directly disposed onto the second major side of the backing. In a particular embodiment, the coated abrasive article 2100 can optionally be attached to a back-up pad (not shown) or a vacuum system (not shown).

Backing

The backing can be flexible or rigid. The backing can be made of any number of various materials including those conventionally used as backings in the manufacture of coated abrasives. An exemplary flexible backing includes a polymeric film (for example, a primed film), such as polyolefin film (e.g., polypropylene including biaxially oriented polypropylene), polyester film (e.g., polyethylene terephthalate), polyamide film, or cellulose ester film; metal foil; mesh; foam (e.g., natural sponge material or polyurethane foam); cloth (e.g., cloth made from fibers or yarns comprising polyester, nylon, silk, cotton, poly-cotton or rayon); paper; vulcanized paper; vulcanized rubber; vulcanized fiber; nonwoven materials; a combination thereof; or a treated version thereof. Cloth backings may be woven or stitch bonded. In particular examples, the backing is selected from the group consisting of paper, polymer film, cloth, cotton, poly-cotton, rayon, polyester, poly-nylon, vulcanized rubber, vulcanized fiber, metal foil and a combination thereof. In other examples, the backing includes polypropylene film or polyethylene terephthalate (PET) film.

The backing may optionally have at least one of a saturant, a presize layer or a backsize layer. The purpose of these layers is typically to seal the backing or to protect yarn or fibers in the backing. If the backing is a cloth material, at least one of these layers is typically used. The addition of the presize layer or backsize layer may additionally result in a "smoother" surface on either the front or the back side of the backing. Other optional layers known in the art can also be used (for example, a tie layer; see U.S. Pat. No. 5,700,302 (Stoetzel et al.), the disclosure of which is incorporated by reference).

An antistatic material may be included in a cloth treatment material. The addition of an antistatic material can reduce the tendency of the coated abrasive article to accumulate static electricity when sanding wood or wood-like materials. Additional details regarding antistatic backings and backing treatments can be found in, for example, U.S. Pat. Nos. 5,108,463 (Buchanan et al.); 5,137,542 (Buchanan et al.); 5,328,716 (Buchanan); and 5,560,753 (Buchanan et al.), the disclosures of which are incorporated herein by reference.

The backing may be a fibrous reinforced thermoplastic such as described, for example, in U.S. Pat. No. 5,417,726 (Stout et al.), or an endless spliceless belt, as described, for example, in U.S. Pat. No. 5,573,619 (Benedict et al.), the disclosures of which are incorporated herein by reference. Likewise, the backing may be a polymeric substrate having hooking stems projecting therefrom such as that described, for example, in U.S. Pat. No. 5,505,747 (Chesley et al.), the disclosure of which is incorporated herein by reference. Similarly, the backing may be a loop fabric such as that described, for example, in U.S. Pat. No. 5,565,011 (Follett et al.), the disclosure of which is incorporated herein by reference.

Abrasive Layer

The abrasive layer may be formed from one or more coats and a plurality of abrasive grains. For example, the abrasive layer includes a make coat _09 and can optionally include a size coat or a supersize coat. Abrasive layers generally include abrasive grains disposed on, embedded within, dispersed within, or combinations thereof, in a binder.

Abrasive Grains

The abrasive grains can include essentially single phase inorganic materials, such as alumina, silicon carbide, silica, ceria, and harder, high performance superabrasive grains such as cubic boron nitride and diamond. Additionally, the abrasive grains can include composite particulate materials. Such materials can include aggregates, which can be formed through slurry processing pathways that include removal of the liquid carrier through volatilization or evaporation, leaving behind green aggregates, optionally followed by high temperature treatment (i.e., firing) to form usable, fired aggregates. Further, the abrasive regions can include engineered abrasives including macrostructures and particular three-dimensional structures.

In an exemplary embodiment, the abrasive grains are blended with the binder formulation to form abrasive slurry. Alternatively, the abrasive grains are applied over the binder formulation after the binder formulation is coated on the backing. Optionally, a functional powder may be applied over the abrasive regions to prevent the abrasive regions from sticking to a patterning tooling. Alternatively, patterns may be formed in the abrasive regions absent the functional powder.

The abrasive grains may be formed of any one of or a combination of abrasive grains, including silica, alumina (fused or sintered), zirconia, zirconia/alumina oxides, silicon carbide, garnet, diamond, cubic boron nitride, silicon nitride, ceria, titanium dioxide, titanium diboride, boron carbide, tin oxide, tungsten carbide, titanium carbide, iron oxide, chromia, flint, emery. For example, the abrasive grains may be selected from a group consisting of silica, alumina, zirconia, silicon carbide, silicon nitride, boron nitride, garnet, diamond, co-fused alumina zirconia, ceria, titanium diboride, boron carbide, flint, emery, alumina nitride, and a blend thereof. Particular embodiments have been created by use of dense abrasive grains comprised principally of alpha-alumina.

The abrasive grain may also have a particular shape. An example of such a shape includes a rod, a triangle, a pyramid, a cone, a solid sphere, a hollow sphere, or the like. Alternatively, the abrasive grain may be randomly shaped.

In an embodiment, the abrasive grains can have an average grain size not greater than 800 microns, such as not greater than about 700 microns, not greater than 500 microns, not greater than 200 microns, or not greater than 100 microns. In another embodiment, the abrasive grain size is at least 0.1 microns, at least 0.25 microns, or at least o.5 microns. In another embodiment, the abrasive grains size is from about 0.1 microns to about 200 microns and more typically from about 0.1 microns to about 150 microns or from about 1 micron to about 100 microns. The grain size of the abrasive grains is typically specified to be the longest dimension of the abrasive grain. Generally, there is a range distribution of grain sizes. In some instances, the grain size distribution is tightly controlled.

Make Coat - Binder

The binder of the make coat or the size coat may be formed of a single polymer or a blend of polymers. For example, the binder may be formed from epoxy, acrylic polymer, or a combination thereof. In addition, the binder may include filler, such as nano-sized filler or a combination of nano-sized filler and micron-sized filler. In a particular embodiment, the binder is a colloidal binder, wherein the formulation that is cured to form the binder is a colloidal suspension including particulate filler. Alternatively, or in addition, the binder may be a nanocomposite binder including sub-micron particulate filler.

The binder generally includes a polymer matrix, which binds abrasive grains to the backing or compliant coat, if present. Typically, the binder is formed of cured binder formulation. In one exemplary embodiment, the binder formulation includes a polymer component and a dispersed phase.

The binder formulation may include one or more reaction constituents or polymer constituents for the preparation of a polymer. A polymer constituent may include a monomeric molecule, a polymeric molecule, or a combination thereof. The binder formulation may further comprise components selected from the group consisting of solvents, plasticizers, chain transfer agents, catalysts, stabilizers, dispersants, curing agents, reaction mediators and agents for influencing the fluidity of the dispersion.

The polymer constituents can form thermoplastics or thermosets. By way of example, the polymer constituents may include monomers and resins for the formation of polyurethane, polyurea, polymerized epoxy, polyester, polyimide, polysiloxanes (silicones), polymerized alkyd, styrene-butadiene rubber, acrylonitrile-butadiene rubber, polybutadiene, or, in general, reactive resins for the production of thermoset polymers. Another example includes an acrylate or a methacrylate polymer constituent. The precursor polymer constituents are typically curable organic material (i.e., a polymer monomer or material capable of polymerizing or crosslinking upon exposure to heat or other sources of energy, such as electron beam, ultraviolet light, visible light, etc., or with time upon the addition of a chemical catalyst, moisture, or other agent which cause the polymer to cure or polymerize). A precursor polymer constituent example includes a reactive constituent for the formation of an amino polymer or an aminoplast polymer, such as alkylated urea-formaldehyde polymer, melamine-formaldehyde polymer, and alkylated benzoguanamine-formaldehyde polymer; acrylate polymer including acrylate and methacrylate polymer, alkyl acrylate, acrylated epoxy, acrylated urethane, acrylated polyester, acrylated polyether, vinyl ether, acrylated oil, or acrylated silicone; alkyd polymer such as urethane alkyd polymer; polyester polymer; reactive urethane polymer; phenolic polymer such as resole and novolac polymer; phenolic/latex polymer; epoxy polymer such as bisphenol epoxy polymer; isocyanate; isocyanurate; polysiloxane polymer including alkylalkoxysilane polymer; or reactive vinyl polymer. The binder formulation may include a monomer, an oligomer, a polymer, or a combination thereof. In a particular embodiment, the binder formulation includes monomers of at least two types of polymers that when cured may crosslink. For example, the binder formulation may include epoxy constituents and acrylic constituents that when cured form an epoxy/acrylic polymer.

Additives - Grinding Aid

The abrasive layer may further include a grinding aid to increase the grinding efficiency and cut rate. A useful grinding aid can be inorganic based, such as a halide salt, for example, sodium cryolite, and potassium tetrafluoroborate; or organic based, such as a chlorinated wax, for example, polyvinyl chloride. A particular embodiment includes cryolite and potassium tetrafluoroborate with particle size ranging from 1 micron to 80 microns, and most typically from 5 microns to 30 microns. The supersize coat can be a polymer layer applied over the abrasive grains to provide anti-glazing and anti-loading properties.

Back Coat - Compliant Coat

The coated abrasive article may optionally include compliant and back coats (not shown). These coats may function as described above and may be formed of binder compositions.

Method of Making – Coated Abrasive Article

Turning to a method of making a coated abrasive article having an abrasive area pattern, a backing can be distributed from a roll, the backing can be coated with a binder formulation dispensed from a coating apparatus. An exemplary coating apparatus includes a drop die coater, a knife coater, a curtain coater, a vacuum die coater or a die coater. Coating methodologies can include either contact or non-contact methods. Such methods include two roll, three roll reverse, knife over roll, slot die, gravure, rotary printing, extrusion, spray coating applications, or combinations thereof.

In an embodiment, the binder formulation can be provided in a slurry including the formulation and abrasive grains. In an alternative embodiment, the binder formulation can be dispensed separate from the abrasive grains. The abrasive grains may be provided following coating of the backing with the binder, after partial curing of the binder formulation, after patterning of the binder formulation, if any, or after fully curing the binder formulation. The abrasive grains may, for example, be applied by a technique, such as electrostatic coating, drop coating, or mechanical projection.

In another embodiment, the backing, coated with the binder and abrasive grains, can be stamped, die-cut, laser cut, or combinations thereof to form the shape of the coated abrasive (e.g., round disc) or a pattern of apertures, if any, that are cut through the coated abrasive.

In another embodiment, the backing can be selectively coated with the binder to leave uncoated regions that are then coated with abrasive grains to form the abrasive areas. For example, the binder can be printed onto the backing, such as by screen printing, offset printing, rotary printing, or flexographic printing. In another example, the binder can be selectively coated using gravure coating, slot die coating, masked spray coating, or the like. Alternatively, a photoresist or UV curable mask can be applied to the backing and developed, such as by photolithography, to mask portions of the backing. In another example, a dewetting compound can be applied to the backing prior to applying the binder.

Method of Use – Abrading a Workpiece

Turning to a method of abrading a work piece, the work piece can be contacted with a coated abrasive. The coated abrasive can be rotated relative to the work piece. For example, the coated abrasive can be mounted on an orbital sander and contacted to the work piece. While abrading the work piece, material abraded from the work piece can accumulate in the open areas between, or adjacent to, the abrasive areas. The accumulated material can be ejected from the face of the coated abrasive by the movement of the coated abrasive during use. Alternately, a vacuum system can be equipped to the abrasive article. The vacuum system can include a back-up pad that is configured to cooperatively function with the abrasive article.

Back-Up Pad

It will be appreciated that back-up pads designed to correspond to coated abrasives having controlled non-uniform distributions of abrasive areas can be successfully used in conjunction with conventional coated abrasives as well as particular coated abrasives having controlled non-uniform distributions of abrasive areas. The inventors have surprisingly discovered that back-up pad embodiments can provide superior swarf removal and promote improved abrasive performance for conventional abrasives.

In an embodiment, the back-up pad can have a pattern of air flow paths that is cooperatively adapted to operate with coated abrasives having a controlled non-uniform distribution pattern. As stated previously, such a back-up can be used in conjunction with a conventional perforated coated abrasive to promote swarf removal and abrasive performance.

In an embodiment, a back-up pad can comprise a pattern of air flow paths, wherein the pattern of air flow paths is generated from x and y co-ordinates of a controlled non-uniform distribution pattern. The controlled non-uniform distribution pattern used to generate the back-up pad air flow pattern can be the same or different than the pattern of the coated abrasive being used with the back-up pad. In an embodiment, the controlled non-uniform distribution pattern is the same as the pattern of the coated abrasive being used with the back-up pad. In another embodiment, the controlled non-uniform distribution pattern is different than the pattern of the coated abrasive being used with the back-up pad.

In an embodiment, a back-up pad can be cooperatively adapted to operate with coated abrasives having phyllotactic patterns according to the coated abrasive embodiments described herein. A back-up pad is co-operative with a coated abrasive having phyllotactic patterns when the back-up pad includes a plurality of openings, a plurality of cavities, a plurality of channels, plurality of passages, or combinations thereof, that are configured in a pattern designed to promote suction and swarf removal away from the work surface during the abrasion process through the apertures of a coated abrasive having a phyllotactic pattern. The openings, cavities, channels, passages, or combinations thereof can define air-flow paths that are located along, within, or though the back-up pad, or combinations thereof. The air-flow paths promote improved suction and swarf removal through the apertures of a coated abrasive and away from the work surface during the abrasion process. In an embodiment, the pattern of openings, cavities, channels, passages or combinations thereof can be in the form of a regular polygons, irregular polygons, ellipsoids, arcs, spirals, phyllotactic patterns, or combinations thereof. In another embodiment, the air-flow paths can be in the form of a regular polygons, irregular polygons, ellipsoids, arcs, spirals, phyllotactic patterns, or combinations thereof.

The patterns can then be used to define radiating accurate and spiral channels, as well as, annular channels that can intersect the arcurate and spiral channels, or combinations thereof. The annular, arcurate, spiral, or combination channels can then be cut into a suitable material, such as in the form of grooves, cavities, orifices, passages, or other pathways to form a co-operative back-up pad.

In certain embodiments, the air-flow paths of the back-up pad will partially, to fully, match-up with the apertures of the coated abrasive. It will be understood that an air-flow path matches-up with an aperture when at least a portion of the area of an aperture coincides with, or is aligned with, a portion of the air-flow path. In an embodiment, the air-flow paths of the corresponding back-up pad will match-up with at least 5%, at least 10%, at least 15%, at least 20%, at least 25% of the apertures. In an embodiment, the air-flow paths of the corresponding back-up pad can match-up with at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 55%, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, or at least 100% of the apertures of the coated abrasive.

It will be appreciated that certain of the back-up pad spiral and phyllotactic air-flow patterns will exhibit a certain quality of alignment with an aperture pattern of a coated abrasive, particularly when the air-flow pattern is based on a transpose and rotation of the co-ordinates of the abrasive areas of the coated abrasive. In an embodiment, the air-flow pattern of the back-up pad will match up with a majority, to nearly all, of the coated abrasive apertures when the back-up pad is in a particular phase, or degrees of rotation, with respect to the coated abrasive. A back-up pad is said to be a single-alignment (also called a 2-fold alignment) back-up pad when the air-flow paths of the back-up pad match up with the apertures of the coated abrasive when the back-up is rotated 90° or 180° compared to the coated abrasive and a majority to nearly all of the apertures of the coated abrasive match-up with at least one of the air-flow paths of the back-up pad.

In an embodiment, the back-up pad can include or be adapted to include an alignment indicator. An alignment indicator can be a marking, device, notch, attachment, collar, protrusion, or combination thereof to indicate the degree of alignment of the back-up pad with the coated abrasive. In a specific embodiment, the alignment indicator can be marking.

Although described as co-operative with the embodiments of the abrasive articles described herein, such back-up pads can also be used with standard state-of-the art perforated coated abrasives.

It has been unexpectedly found that back-up pads having a plurality of openings, a plurality of cavities, a plurality of channels, or combinations thereof that form suitable spiral or phyllotactic pattern air-flow paths have improved swarf removal, can promote abrasive cutting performance, and abrasive lifespan for both standard state-of-the art perforated coated abrasives and coated abrasives having phyllotactic patterns of perforations.

A back-up pad can be flexible or rigid. The back-up pad can be made of any number of various materials, or combinations of materials, including those conventionally used in the manufacture of back-up pads. The back-up pad can be made of single piece, unitary construction, or multi-piece construction, such as multi-layer construction or concentric layer construction. The back-up pad is preferably a resilient material such as a flexible foam. Suitable foams can be polyurethane, polyester, polyester-urethane, polyetherurethane; a natural or artificial rubber such as a polybutadiene, polyisoprene, EPDM polymer, polyvinylchloride (PVC), polychroloprene, or styrene/butadiene copolymer; or combinations thereof. The foam can be open or closed cell. Additives, such as coupling agents, toughening agents, curing agents, antioxidants, reinforcing materials, and the like can be added to the foam formulation to achieve desired characteristics. Dyes, pigments, fillers, anti-static agents, fire retardants, and scrim can also be added to the foam or other resilient material used to make the back-up pad.

Particularly useful foams include TDI (toluene diisocyanate)/polyester and MDI (methylene diphenyl diisocyanate)/polyester foams. In an embodiment, the back-up pad is made of resilient, open cell polyurethane foam formed as the reaction product of a polyether polyol and an aromatic polyisocyanate. In another embodiment, the back-up pad can be a foam, a vulcanized rubber, or any combination thereof.

Note that not all of the activities described above in the general description or the examples are required, that a portion of a specific activity may not be required, and that one or more further activities may be performed in addition to those described. Still further, the order in which activities are listed are not necessarily the order in which they are performed.

In the foregoing specification, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of invention.

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

Also, the use of "a" or "an" are employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

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

After reading the specification, skilled artisans will appreciate that certain features are, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination.

Further, references to values stated in ranges include each and every value within that range. When the terms "about" or "approximately" precede a numerical value, such as when describing a numerical range, it is intended that the exact numerical value is also included. For example, a numerical range beginning at "about 25" is intended to also include a range that begins at exactly 25.

Item 1. An abrasive article comprising:
a coated abrasive having a plurality of abrasive areas arranged in a pattern,
wherein the pattern has a controlled non-uniform distribution, and
wherein the pattern is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

Item 2. The abrasive article of item 1, wherein the pattern is a spiral pattern.

Item 3. The abrasive article of item 2, wherein the spiral pattern is one of an Archimedean spiral, a Euler spiral, a Fermat's spiral, a hyperbolic spiral, a lituus, a logarithmic spiral, a Fibonacci spiral, a golden spiral, or combinations thereof.

Item 4. The abrasive article of item 3, wherein the pattern has a controlled asymmetry.

Item 5. The abrasive article of item 4, wherein the controlled asymmetry is an at least partial rotational asymmetry about the center of the pattern.

Item 6. The abrasive article of item 5, wherein the rotational asymmetry extends to at least 51%, at least 70%, or at least 85% of the abrasive areas of the pattern.

Item 7. The abrasive article of item 5, wherein the rotational asymmetry extends to at least 20 abrasive areas, at least 50 abrasive areas, or at least 100 abrasive areas of the pattern.

Item 8. The abrasive article of item 5, wherein the pattern is rotationally asymmetric about the center of the pattern.

Item 9. The abrasive article of item 1, wherein the pattern is a phyllotactic pattern.

Item 10. The abrasive article of item 9, wherein the pattern is a spiral phyllotactic pattern.

Item 11. The abrasive article of item 10, wherein the pattern has a number of clockwise spirals and a number of counter-clock wise spirals, wherein the number of clockwise spirals and the number of counterclockwise spirals are Fibonacci numbers or multiples of Fibonacci numbers.

Item 12. The abrasive article of item 11, wherein the number of clockwise spirals and the number of counterclockwise spirals are Lucas numbers or multiples of Lucas numbers.

Item 13. The abrasive article of item 11, wherein the number of clockwise spirals and the number of counterclockwise spirals are in a ratio that converges on the golden ratio.

Item 14. The abrasive article of item 10, wherein the spiral phyllotactic pattern has a controlled asymmetry.

Item 15. The abrasive article of item 10, wherein the spiral phyllotactic pattern is a sunflower pattern.

Item 16. The abrasive article of item 11, wherein the pattern is described in polar co-ordinates by the following equation:

$$\varphi = n * \alpha, \qquad r = c\sqrt{n} \quad \text{(Eq. 1)}$$

where:

n is the ordering number of an abrasive area, counting outward from the center of the pattern;

φ is the angle between a reference direction and a position vector of the n^{th} abrasive area in a polar coordinate system originating at the center of the pattern, such that the divergence angle between the position vectors of any two successive abrasive areas is a constant angle α;

r is the distance from the center of the pattern to the center of the n^{th} abrasive area; and

c is a constant scaling factor.

Item 17. The abrasive article of item 16, wherein at least about 51%, at least about 70%, at least about 85% of the abrasive areas conform to Eq.1.

Item 18. The abrasive article of item 16, wherein the pattern has a divergence angle in polar co-ordinates that ranges from about 100° to about 170°.

Item 19. The abrasive article of item 16, wherein the pattern has a divergence angle that is 137.508°.

Item 20. The abrasive article of item 16, wherein at least about 80%, at least about 85%, at least about 90% of the total abrasive area conforms to Eq.1.

Item 21. The abrasive article of item 16, wherein the plurality of abrasive areas ranges from about 5/10/20 abrasive areas to about 500/1000/10,000 abrasive areas.

Item 22. The abrasive article of item 16, wherein the pattern covers substantially the entire face of the abrasive article.

Item 23. The abrasive article of item 16, wherein an edge of an outermost abrasive area of the pattern intersects the edge of the abrasive article.

Item 24. The abrasive article of item 16, wherein an edge of an outermost abrasive area of the pattern is at least a specific distance from the edge of the abrasive article.

Item 25. The abrasive article of item 16, wherein the pattern covers only a portion of the face of the abrasive article.

Item 26. The abrasive article of item 16, wherein the pattern covers periodic portions of the face of the abrasive article.

Item 27. The abrasive article of item 16, wherein the pattern has a total open area of about 15% to about 99.5 % of the surface potential surface area of the abrasive article.

Item 28. The abrasive article of item 16, having a total abrasive surface area that ranges from about 4.5% to about 85% of the total potential surface area.

Item 29. The abrasive article of item 16, having the shape of a disc.

Item 30. The abrasive article of item 16, wherein the abrasive areas have a shape selected from one of short line segments, polygons, ellipsoids, circles, arcs, spirals, whorls, a spiral lattice, or combinations thereof.

Item 31. A coated abrasive article comprising:

a backing layer having a first major side and a second major side; and

an abrasive layer disposed on the first major side of the backing layer,

wherein the abrasive layer comprises a plurality of abrasive areas arranged in a pattern having a controlled non-uniform distribution, and is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

Item 32. A method of making an abrasive article comprising:

disposing an abrasive layer on a backing;

wherein the abrasive layer comprises a plurality of abrasive areas arranged in a pattern having a controlled non-uniform distribution that is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

Item 33. A coated abrasive article comprising:

a plurality of abrasive areas disposed on a major surface of the coated abrasive article, wherein the abrasive areas are configured to form a plurality of air flow paths comprising arcs, spirals, whorls, phyllotactic patterns, or combinations thereof.

Item 34. The coated abrasive of item 34, wherein the pattern of air flow paths comprises radiating arcurate paths, radiating spiral paths, or combinations thereof.

Item 35. The coated abrasive of item 34, wherein the pattern of air flow paths comprises a combination of inner radiating spiral paths and outer radiating spiral paths.

Item 36. The coated abrasive of item 34, wherein the pattern of air flow paths comprises a combination of clock-wise radiating spiral paths and counter clock-wise radiating spiral paths.

Item 37. The coated abrasive of item 34, wherein the pattern of air flow paths further comprises an annular airflow path that intersects the radiating arcurate paths or radiating spiral paths, or combinations thereof.

Item 38. The coated abrasive comprising a pattern of air flow paths, wherein the pattern of air flow paths is generated from *x* and *y* co-ordinates of a controlled non-uniform distribution pattern.

Item 39. The coated abrasive of item 38, wherein the x and y co-ordinates of the controlled non-uniform distribution pattern are transposed and rotated according to the equation (Eq. 2) below, to determine *x'* and y' co-ordinates of the pattern of air flow paths, wherein θ is equal to π/n in radians and n is any integer:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad \text{(Eq. 2)}$$

Item 40. The coated abrasive of item 39, wherein the controlled non-uniform distribution pattern is a phyllotactic pattern.

Item 41. The coated abrasive of item 40, wherein the controlled non-uniform distribution pattern is the Vogel equation.

Item 42. The coated abrasive of item 41, wherein n is any integer from 1 to 10.

Item 43. The coated abrasive of item 42, wherein n is 1, 2, 3, 4, 5, or 6.

Item 44. The coated abrasive of item 39, wherein the pattern of air flow paths comprises a plurality of openings, cavities, channels, passages, or combinations thereof

Item 45. An abrasive system comprising:
a coated abrasive; and a back-up pad, wherein the coated abrasive comprises a controlled non-uniform distribution pattern of abrasive areas, and wherein the back-up pad comprises a plurality of air flow paths disposed in a pattern adapted to correspond with the abrasive areas of the coated abrasive.

CLAIMS:

1. An abrasive article comprising:

a coated abrasive having a plurality of abrasive areas arranged in a pattern,

wherein the pattern has a controlled non-uniform distribution, and

wherein the pattern is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

2. The abrasive article of claim 1, wherein the pattern is a spiral pattern.

3. The abrasive article of claim 2, wherein the spiral pattern is one of an Archimedean spiral, a Euler spiral, a Fermat's spiral, a hyperbolic spiral, a lituus, a logarithmic spiral, a Fibonacci spiral, a golden spiral, or combinations thereof.

4. The abrasive article of claim 3, wherein the pattern has a controlled asymmetry.

5. The abrasive article of claim 4, wherein the controlled asymmetry is an at least partial rotational asymmetry about the center of the pattern.

6. The abrasive article of claim 5, wherein the rotational asymmetry extends to at least 51%, at least 70%, or at least 85% of the abrasive areas of the pattern.

7. The abrasive article of claim 5, wherein the rotational asymmetry extends to at least 20 abrasive areas, at least 50 abrasive areas, or at least 100 abrasive areas of the pattern.

8. The abrasive article of claim 5, wherein the pattern is rotationally asymmetric about the center of the pattern.

9. The abrasive article of claim 1, wherein the pattern is a phyllotactic pattern.

10. The abrasive article of claim 9, wherein the pattern is a spiral phyllotactic pattern.

11. The abrasive article of claim 10, wherein the pattern has a number of clockwise spirals and a number of counter-clock wise spirals, wherein the number of clockwise spirals and the number of counterclockwise spirals are Fibonacci numbers or multiples of Fibonacci numbers.

12. The abrasive article of claim 11, wherein the number of clockwise spirals and the number of counterclockwise spirals are Lucas numbers or multiples of Lucas numbers.

13. The abrasive article of claim 11, wherein the number of clockwise spirals and the number of counterclockwise spirals are in a ratio that converges on the golden ratio.

14. The abrasive article of claim 10, wherein the spiral phyllotactic pattern has a controlled asymmetry.

15. The abrasive article of claim 10, wherein the spiral phyllotactic pattern is a sunflower pattern.

16. The abrasive article of claim 11, wherein the pattern is described in polar co-ordinates by the following equation:

$$\varphi = n * \alpha, \qquad r = c\sqrt{n} \quad \text{(Eq. 1)}$$

where:

n is the ordering number of an abrasive area, counting outward from the center of the pattern;

φ is the angle between a reference direction and a position vector of the n^{th} abrasive area in a polar coordinate system originating at the center of the pattern, such that the divergence angle between the position vectors of any two successive abrasive areas is a constant angle α;

r is the distance from the center of the pattern to the center of the n^{th} abrasive area; and

c is a constant scaling factor.

17. The abrasive article of claim 16, wherein at least about 51%, at least about 70%, at least about 85% of the abrasive areas conform to Eq.1.

18. The abrasive article of claim 16, wherein the pattern has a divergence angle in polar co-ordinates that ranges from about 100° to about 170°.

19. The abrasive article of claim 16, wherein the pattern has a divergence angle that is 137.508°.

20. The abrasive article of claim 16, wherein at least about 80%, at least about 85%, at least about 90% of the total abrasive area conforms to Eq.1.

21. The abrasive article of claim 16, wherein the plurality of abrasive areas ranges from about 5/10/20 abrasive areas to about 500/1000/10,000 abrasive areas.

22. The abrasive article of claim 16, wherein the pattern covers substantially the entire face of the abrasive article.

23. The abrasive article of claim 16, wherein an edge of an outermost abrasive area of the pattern intersects the edge of the abrasive article.

24. The abrasive article of claim 16, wherein an edge of an outermost abrasive area of the pattern is at least a specific distance from the edge of the abrasive article.

25. The abrasive article of claim 16, wherein the pattern covers only a portion of the face of the abrasive article.

26. The abrasive article of claim 16, wherein the pattern covers periodic portions of the face of the abrasive article.

27. The abrasive article of claim 16, wherein the pattern has a total open area of about 15% to about 99.5 % of the surface potential surface area of the abrasive article.

28. The abrasive article of claim 16, having a total abrasive surface area that ranges from about 4.5% to about 85% of the total potential surface area.

29. The abrasive article of claim 16, having the shape of a disc.

30. The abrasive article of claim 16, wherein the abrasive areas have a shape selected from one of short line segments, polygons, ellipsoids, circles, arcs, spirals, whorls, a spiral lattice, or combinations thereof.

31. A coated abrasive article comprising:

a backing layer having a first major side and a second major side; and

an abrasive layer disposed on the first major side of the backing layer, wherein the abrasive layer comprises a plurality of abrasive areas arranged in a pattern having a controlled non-uniform distribution, and is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

32. A method of making an abrasive article comprising:
disposing an abrasive layer on a backing;
wherein the abrasive layer comprises a plurality of abrasive areas arranged in a pattern having a controlled non-uniform distribution that is at least one of a radial pattern, a spiral pattern, a phyllotactic pattern, an asymmetric pattern, or combinations thereof.

33. A coated abrasive article comprising:
a plurality of abrasive areas disposed on a major surface of the coated abrasive article, wherein the abrasive areas are configured to form a plurality of air flow paths comprising arcs, spirals, whorls, phyllotactic patterns, or combinations thereof.

34. The coated abrasive of claim 34, wherein the pattern of air flow paths comprises radiating arcurate paths, radiating spiral paths, or combinations thereof.

35. The coated abrasive of claim 34, wherein the pattern of air flow paths comprises a combination of inner radiating spiral paths and outer radiating spiral paths.

36. The coated abrasive of claim 34, wherein the pattern of air flow paths comprises a combination of clock-wise radiating spiral paths and counter clock-wise radiating spiral paths.

37. The coated abrasive of claim 34, wherein the pattern of air flow paths further comprises an annular airflow path that intersects the radiating arcurate paths or radiating spiral paths, or combinations thereof.

38. The coated abrasive comprising a pattern of air flow paths, wherein the pattern of air flow paths is generated from x and y co-ordinates of a controlled non-uniform distribution pattern.

39. The coated abrasive of claim 38, wherein the x and y co-ordinates of the controlled non-uniform distribution pattern are transposed and rotated according to the equation (Eq. 2) below, to determine x' and y' co-ordinates of the pattern of air flow paths, wherein θ is equal to π/n in radians and n is any integer:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad \text{(Eq. 2)}$$

40. The coated abrasive of claim 39, wherein the controlled non-uniform distribution pattern is a phyllotactic pattern.

41. The coated abrasive of claim 40, wherein the controlled non-uniform distribution pattern is the Vogel equation.

42. The coated abrasive of claim 41, wherein n is any integer from 1 to 10.

43. The coated abrasive of claim 42, wherein n is 1, 2, 3, 4, 5, or 6.

44. The coated abrasive of claim 39, wherein the pattern of air flow paths comprises a plurality of openings, cavities, channels, passages, or combinations thereof

45. An abrasive system comprising:

a coated abrasive; and

a back-up pad,

wherein the coated abrasive comprises a controlled non-uniform distribution pattern of abrasive areas, and

wherein the back-up pad comprises a plurality of air flow paths disposed in a pattern adapted to correspond with the abrasive areas of the coated abrasive.

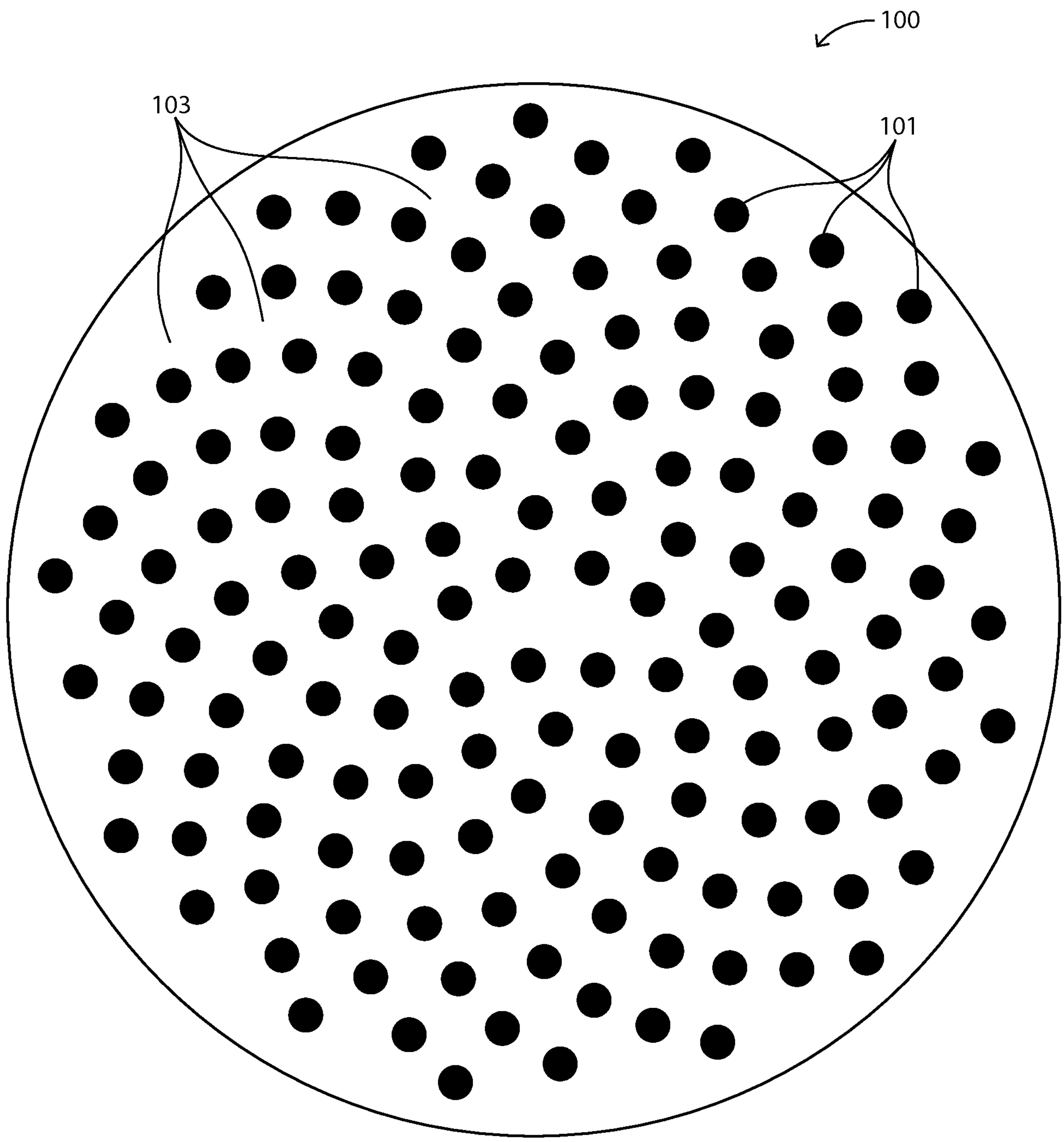

FIG. 1

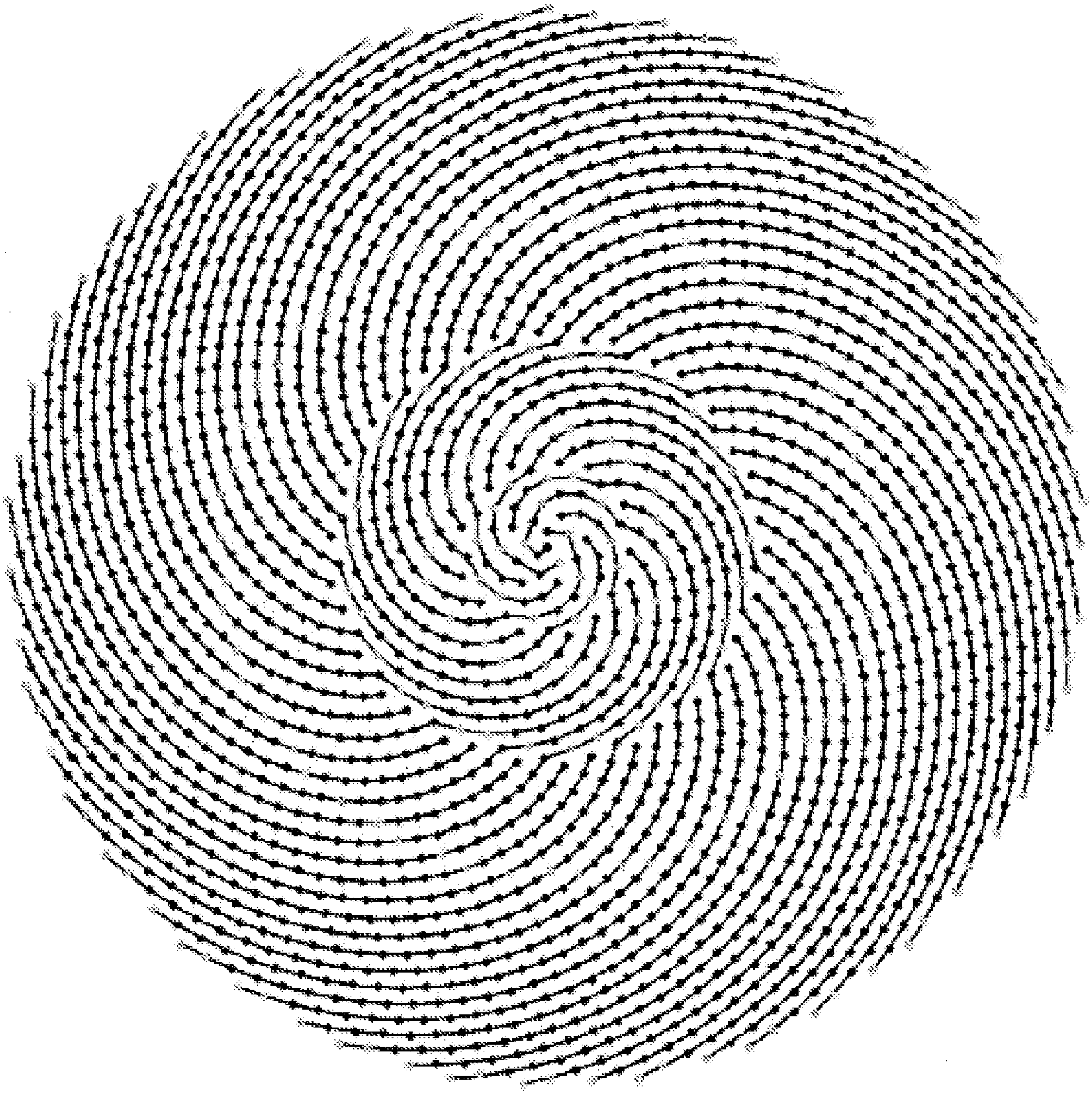

FIG. 2

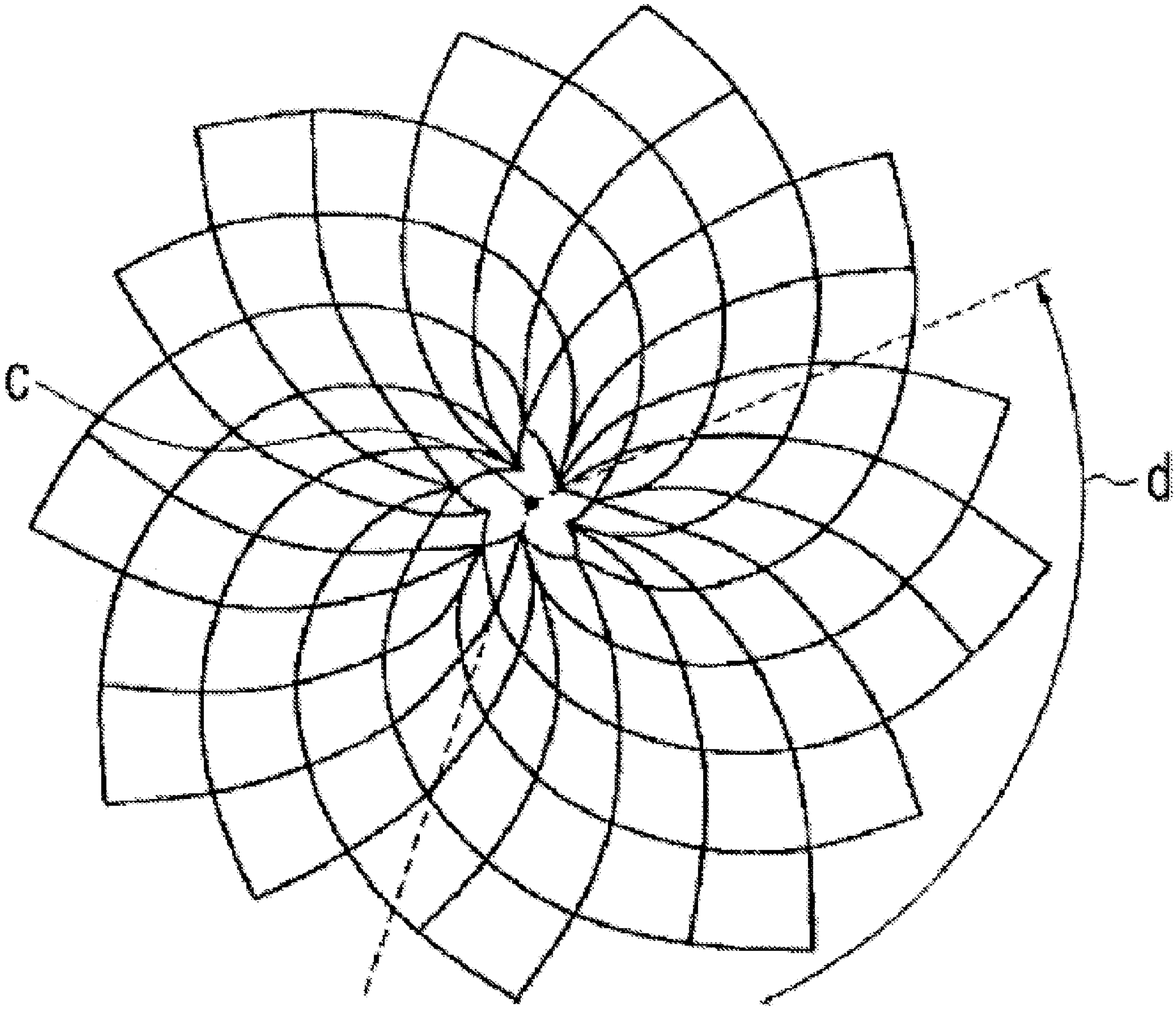

FIG. 3

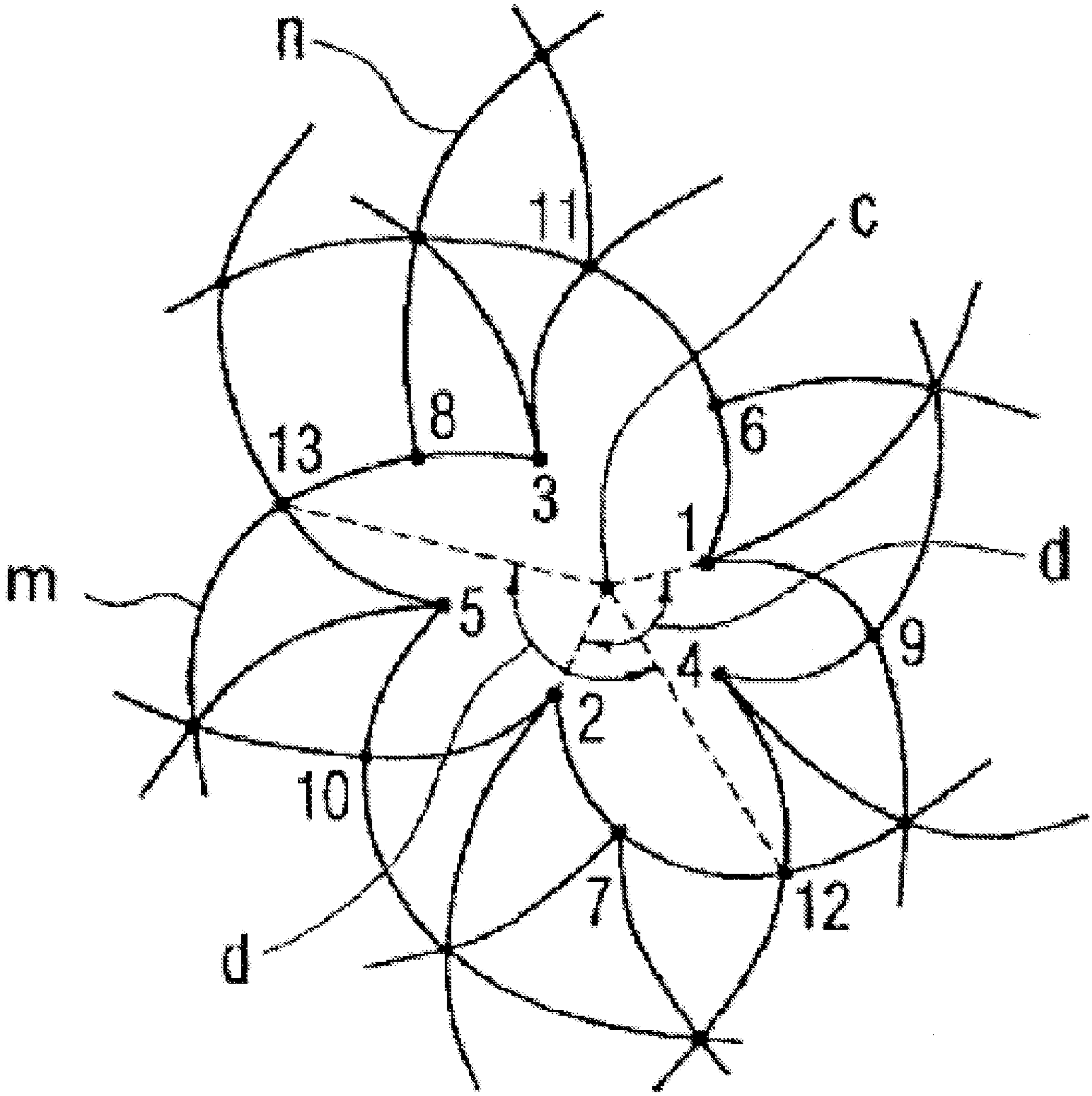

FIG. 4

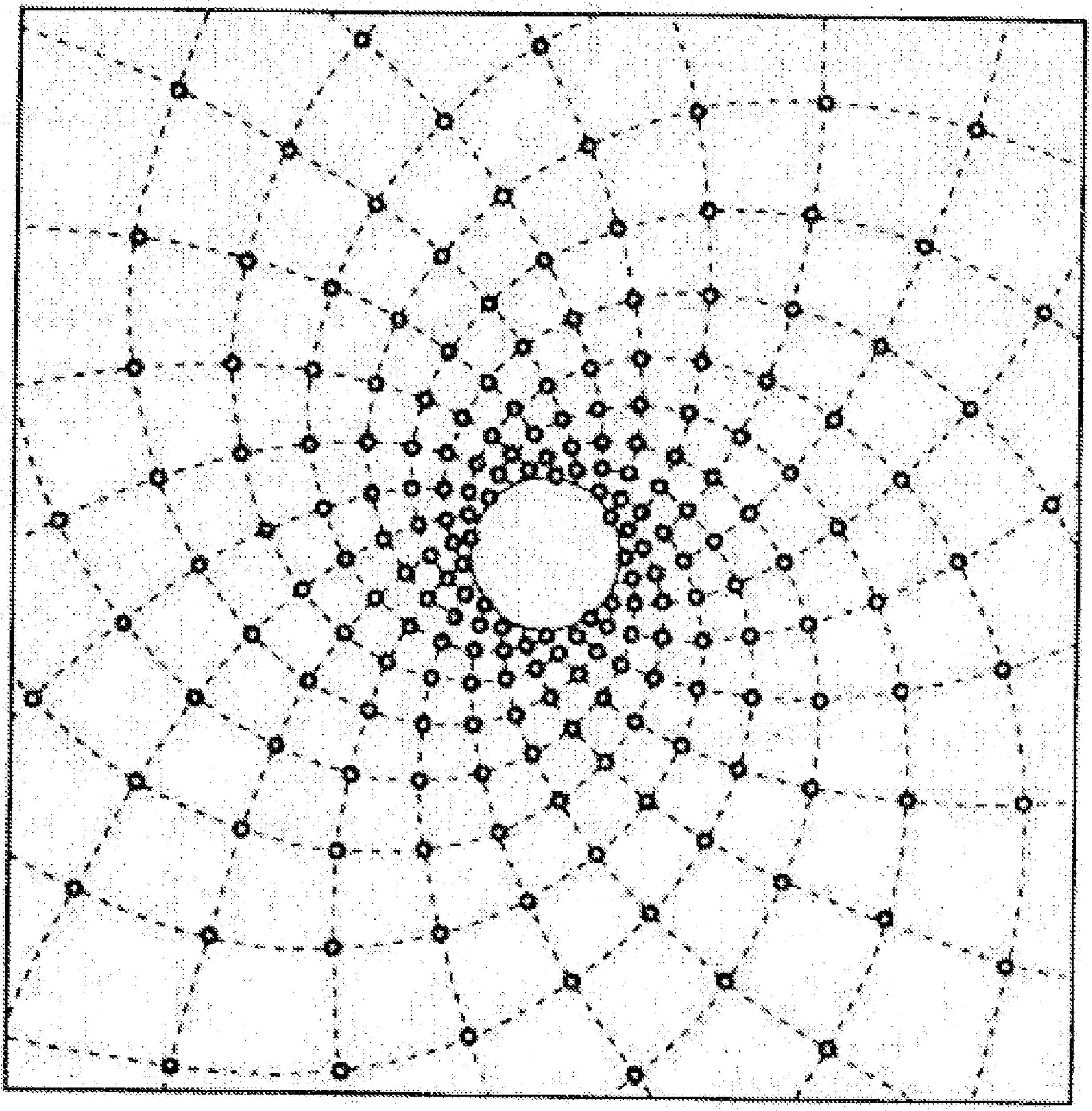

FIG. 5

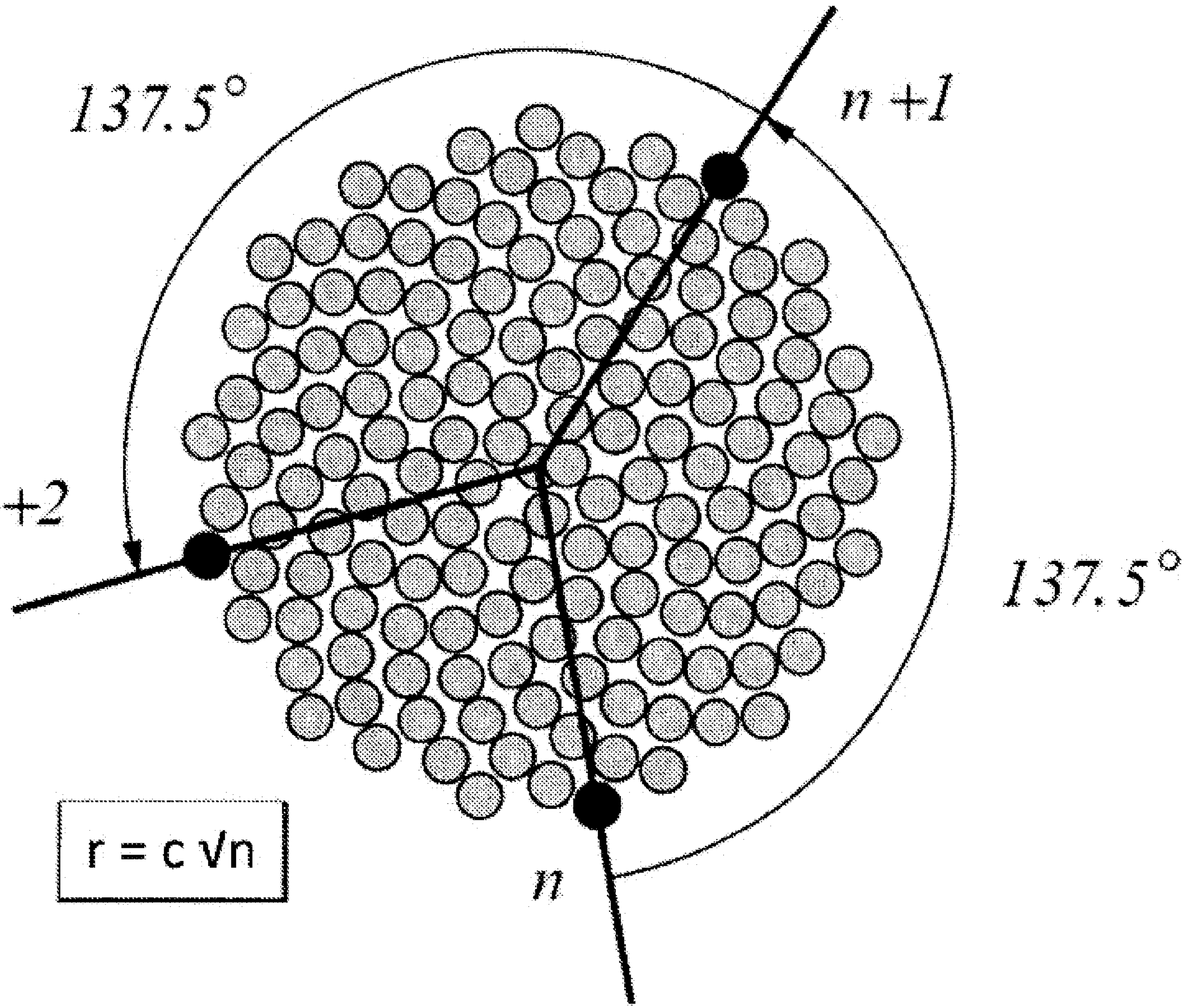

FIG. 6

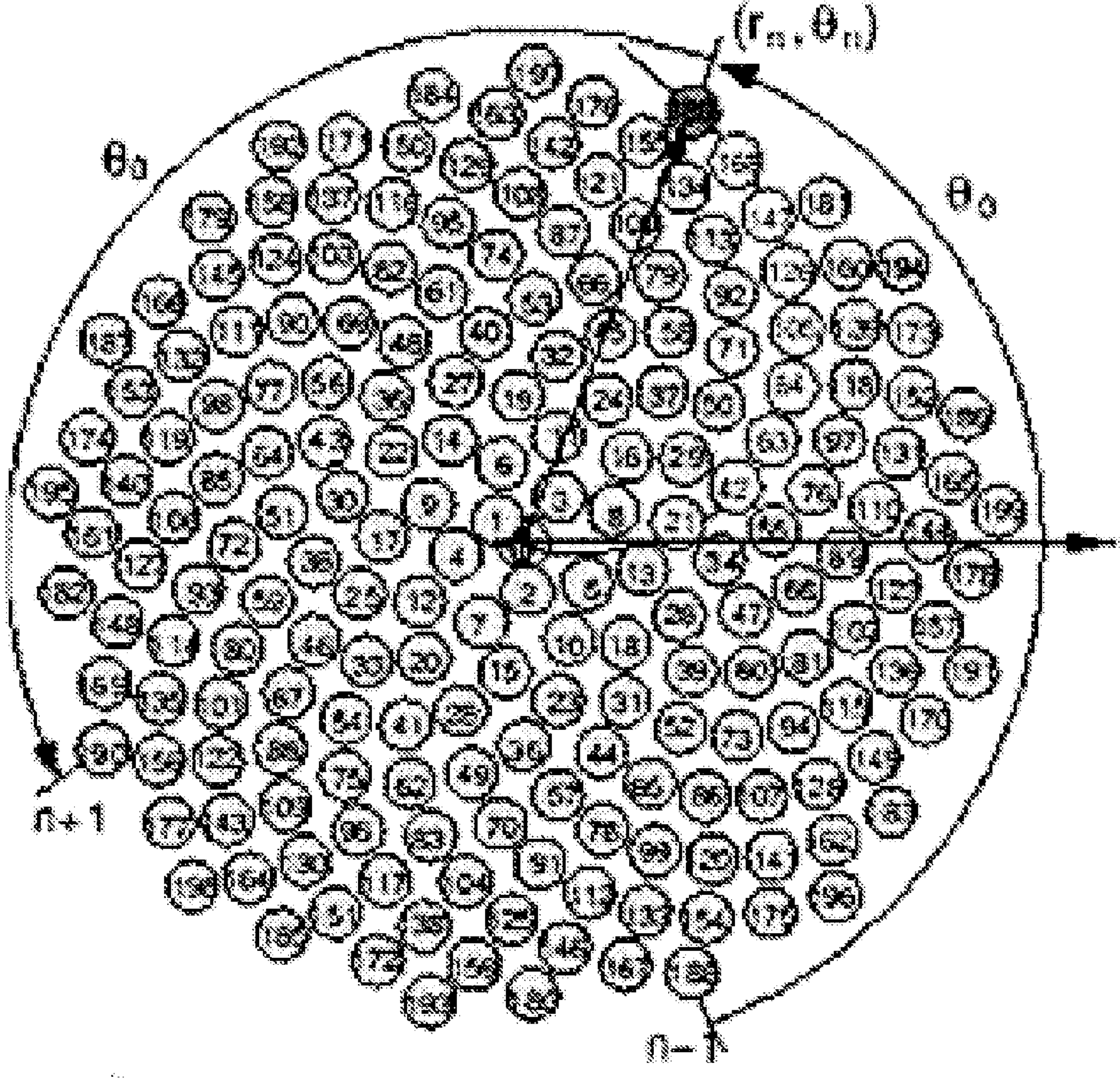

FIG. 7

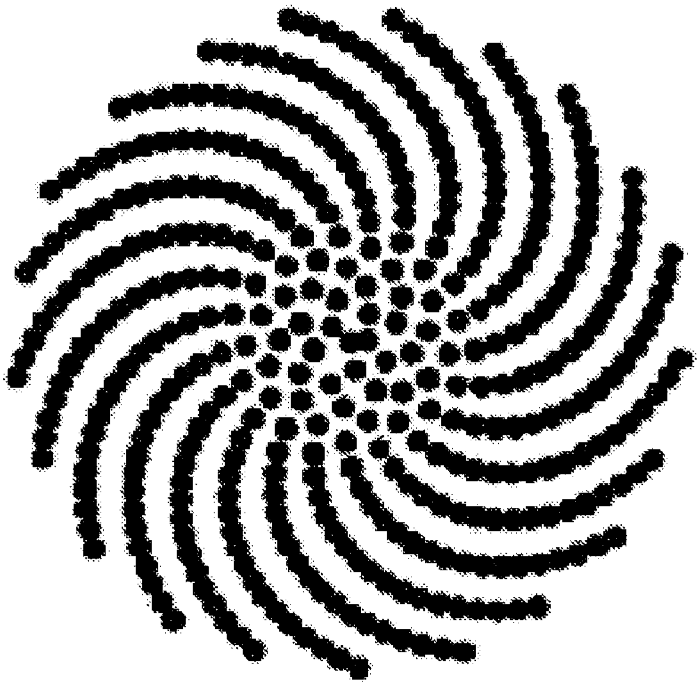

FIG. 8A

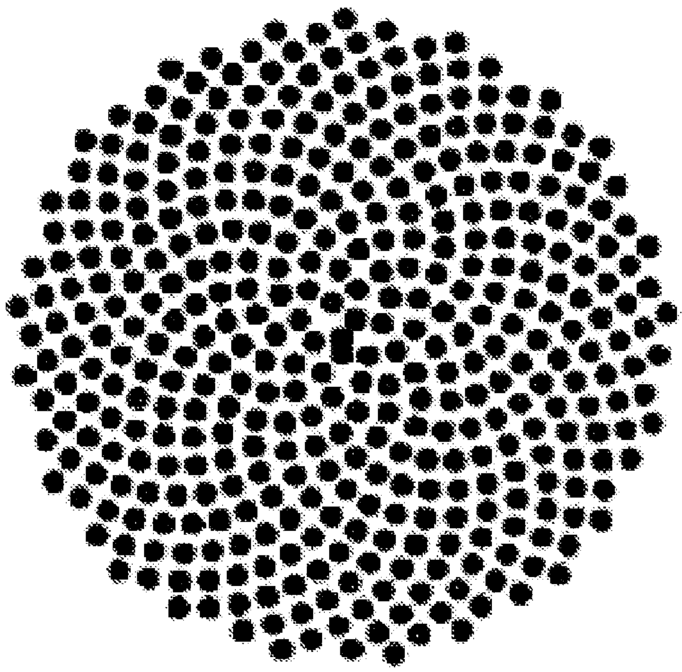

FIG. 8B

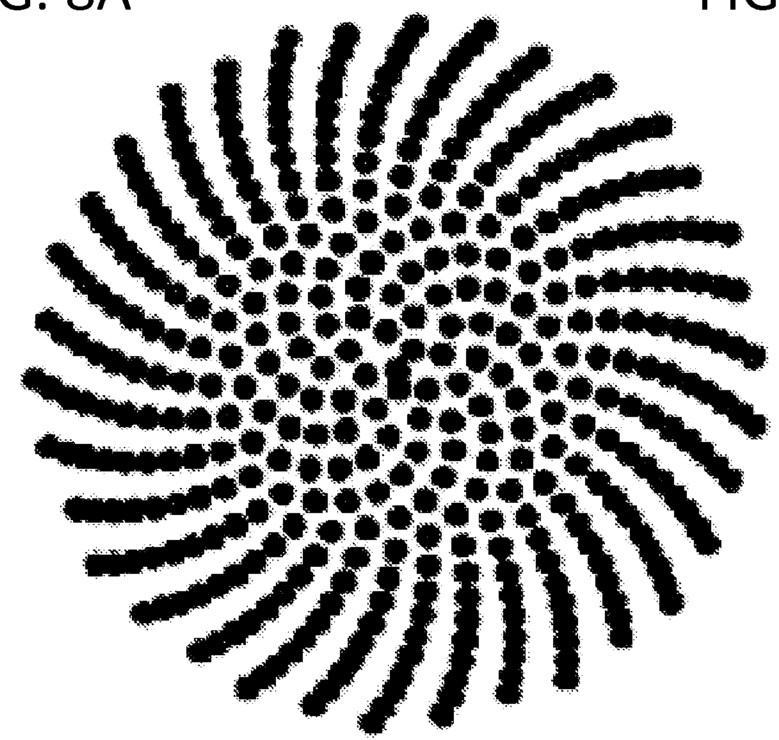

FIG. 8C

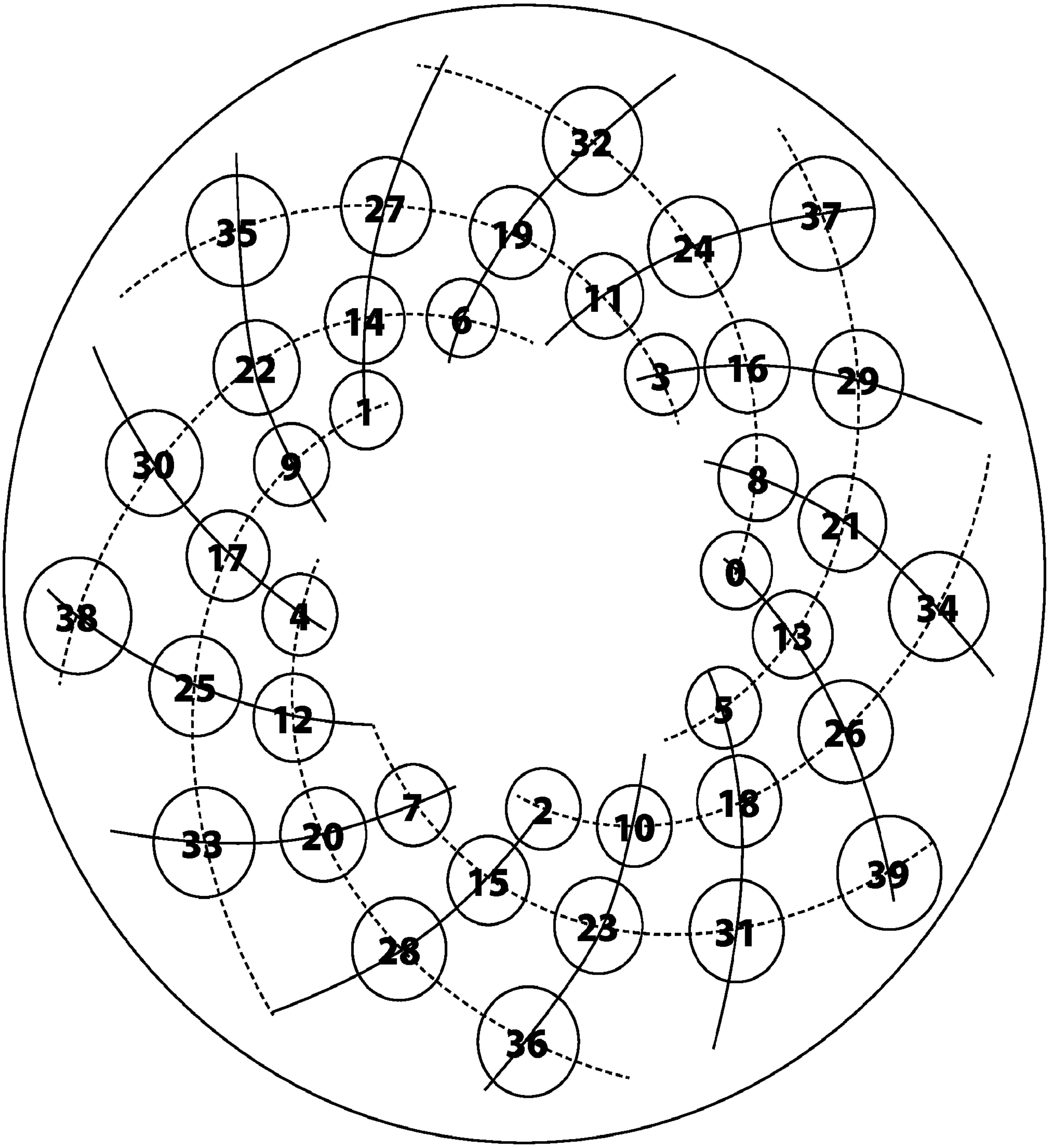
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FIG. 9

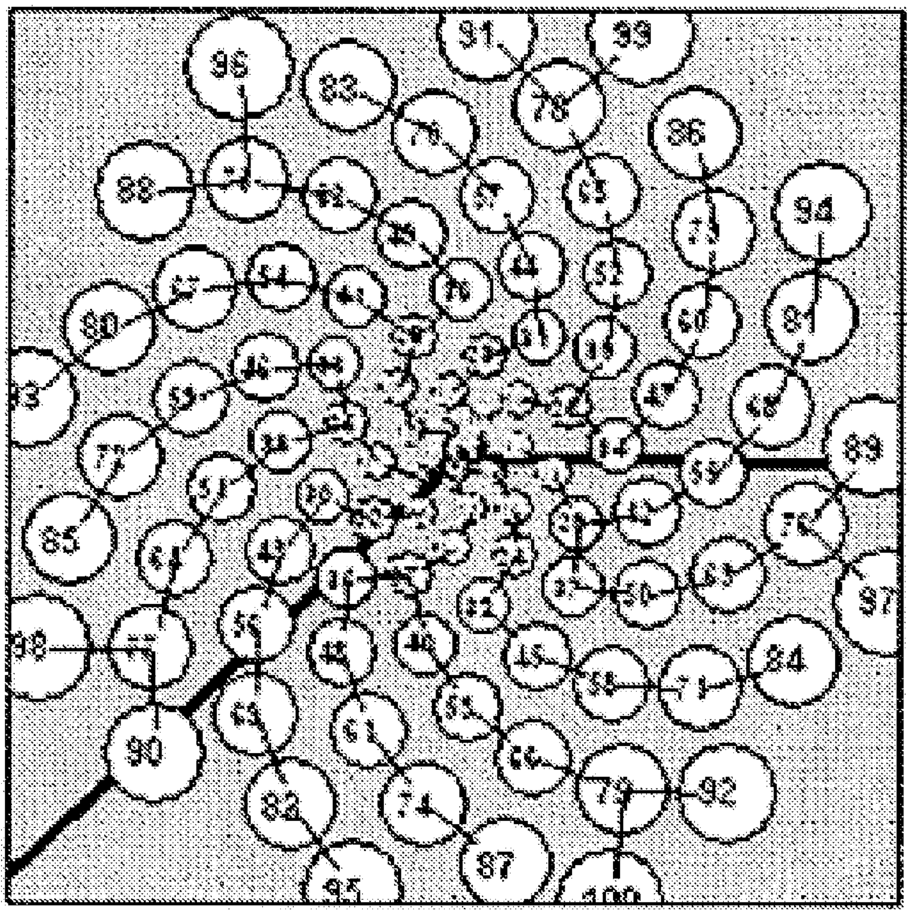

FIG. 10

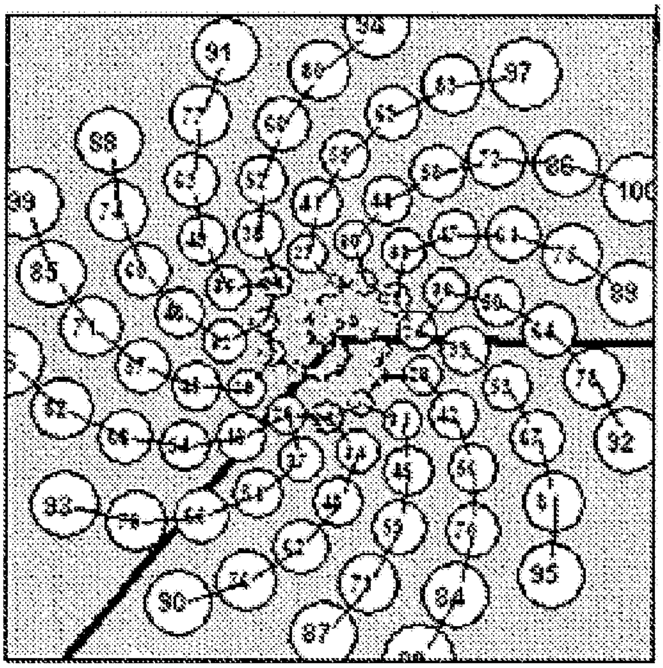

FIG. 11

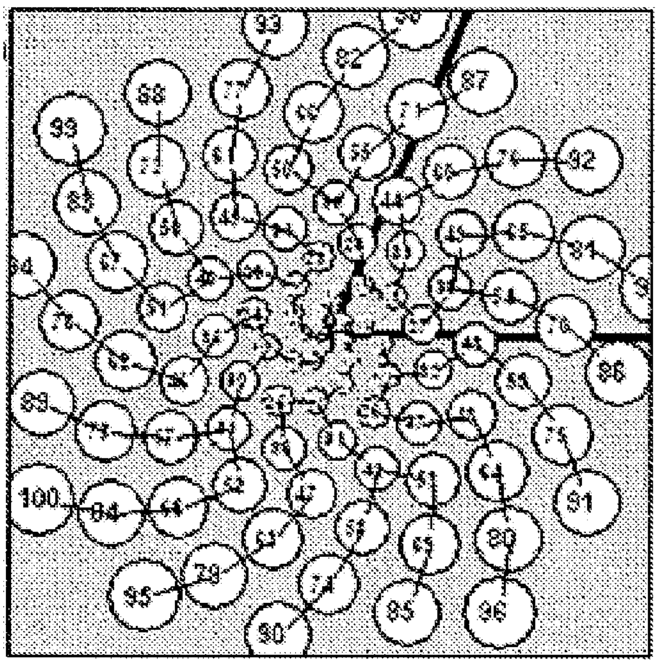

FIG. 12

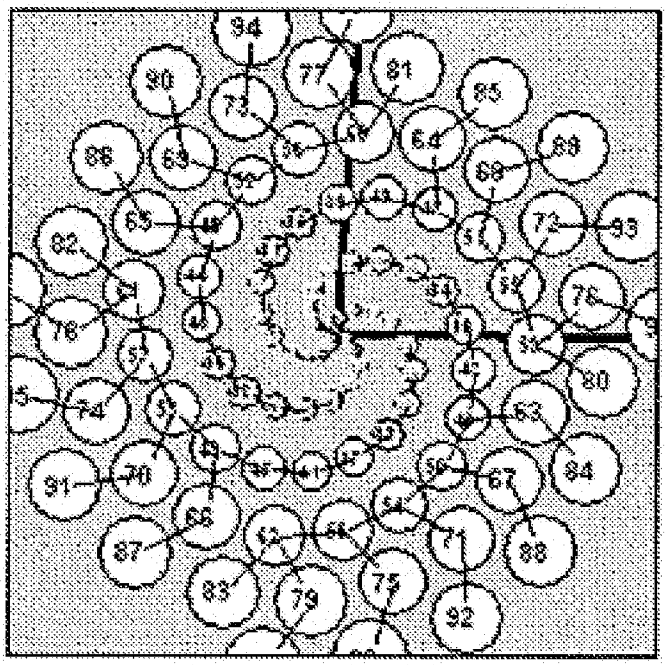
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FIG. 13

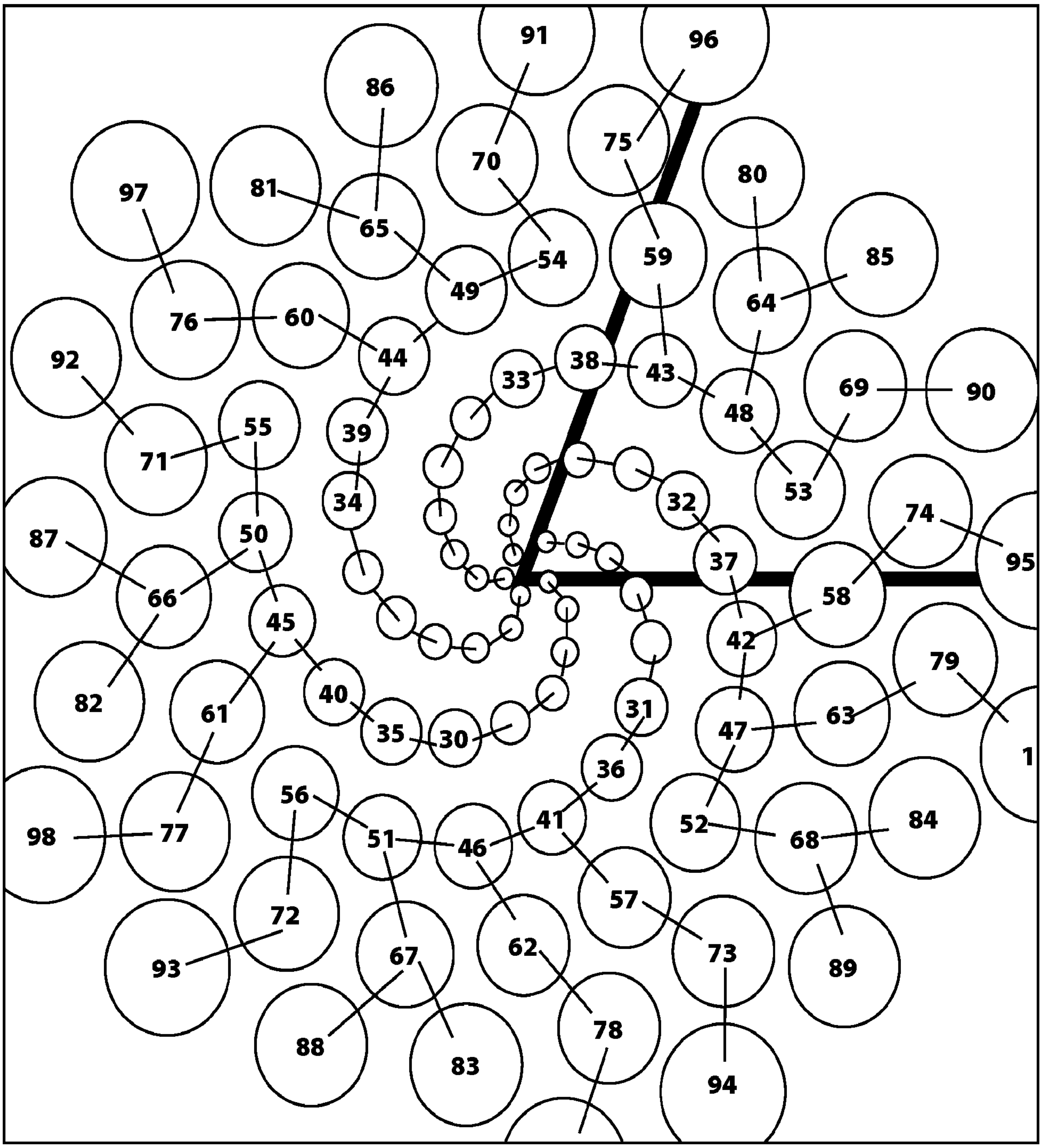
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FIG. 14

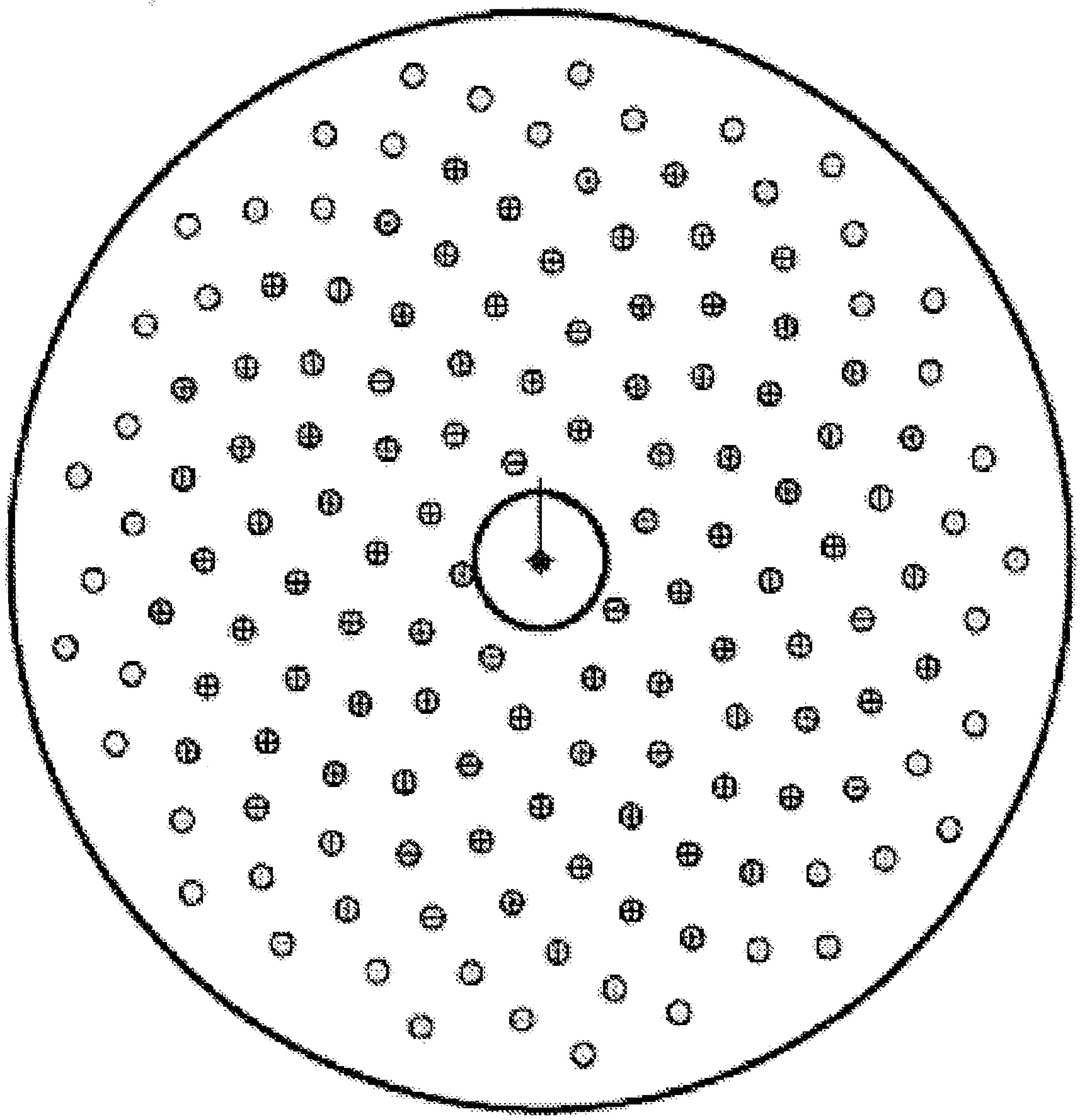

FIG. 15

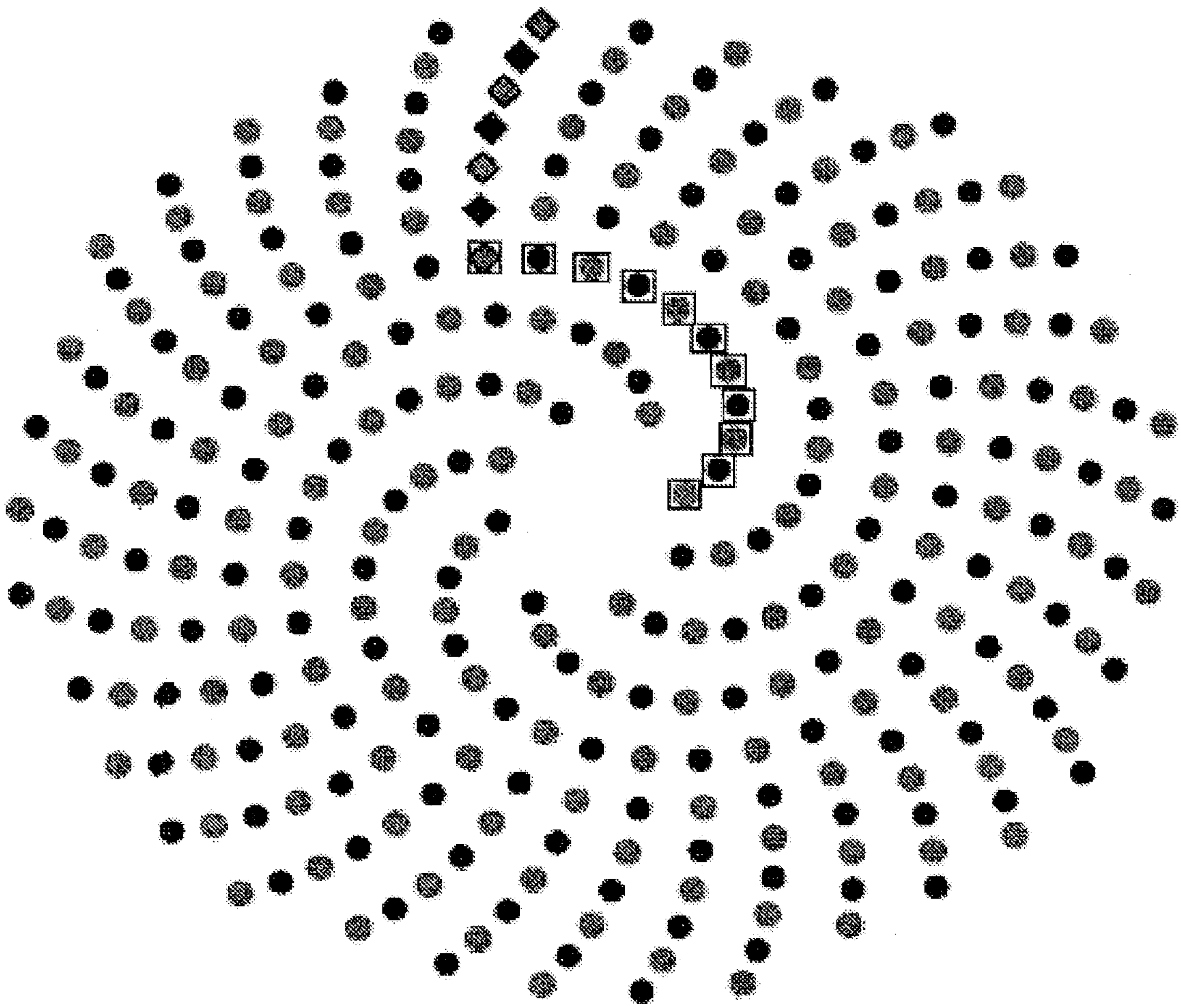

FIG. 16

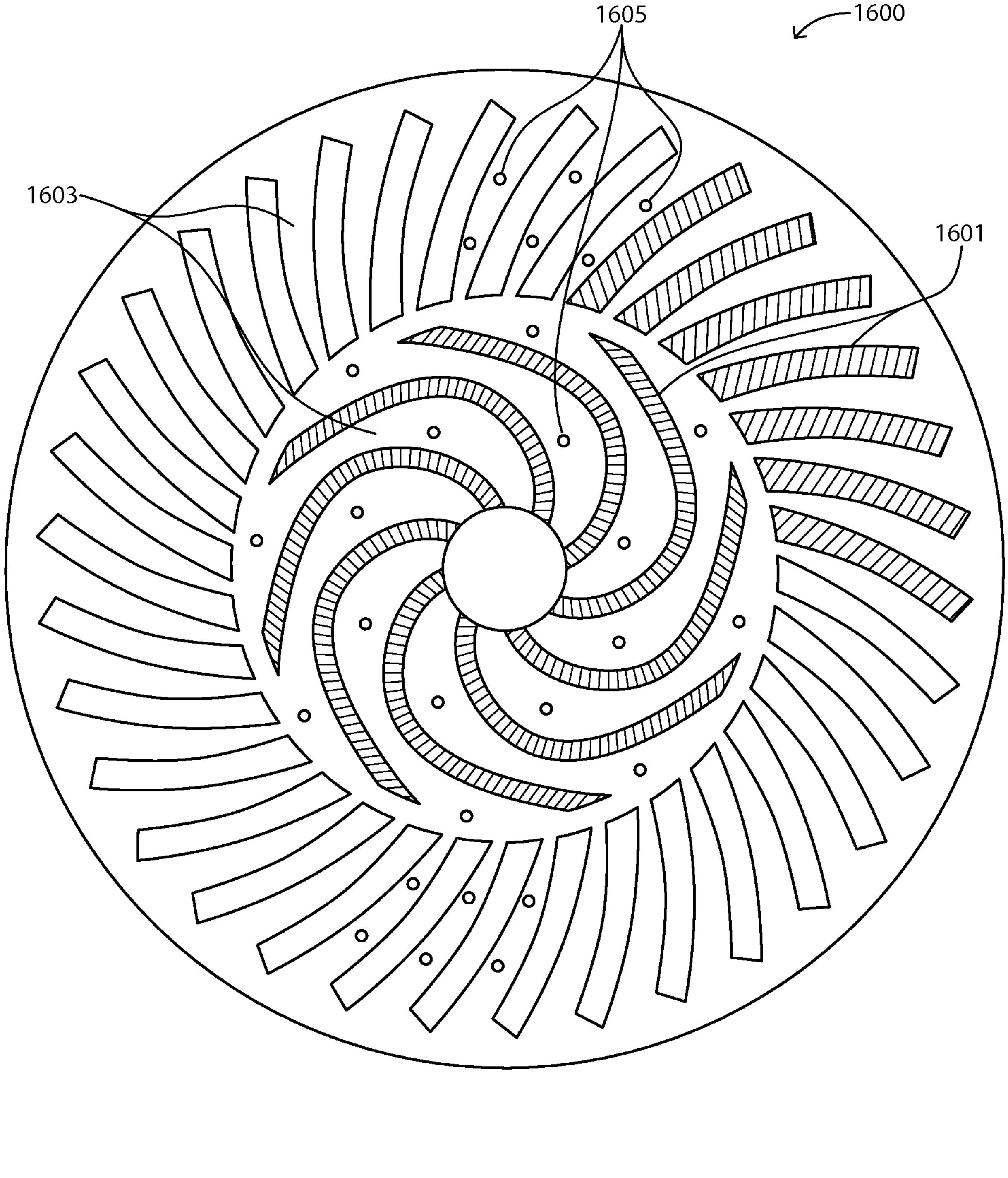

FIG. 17

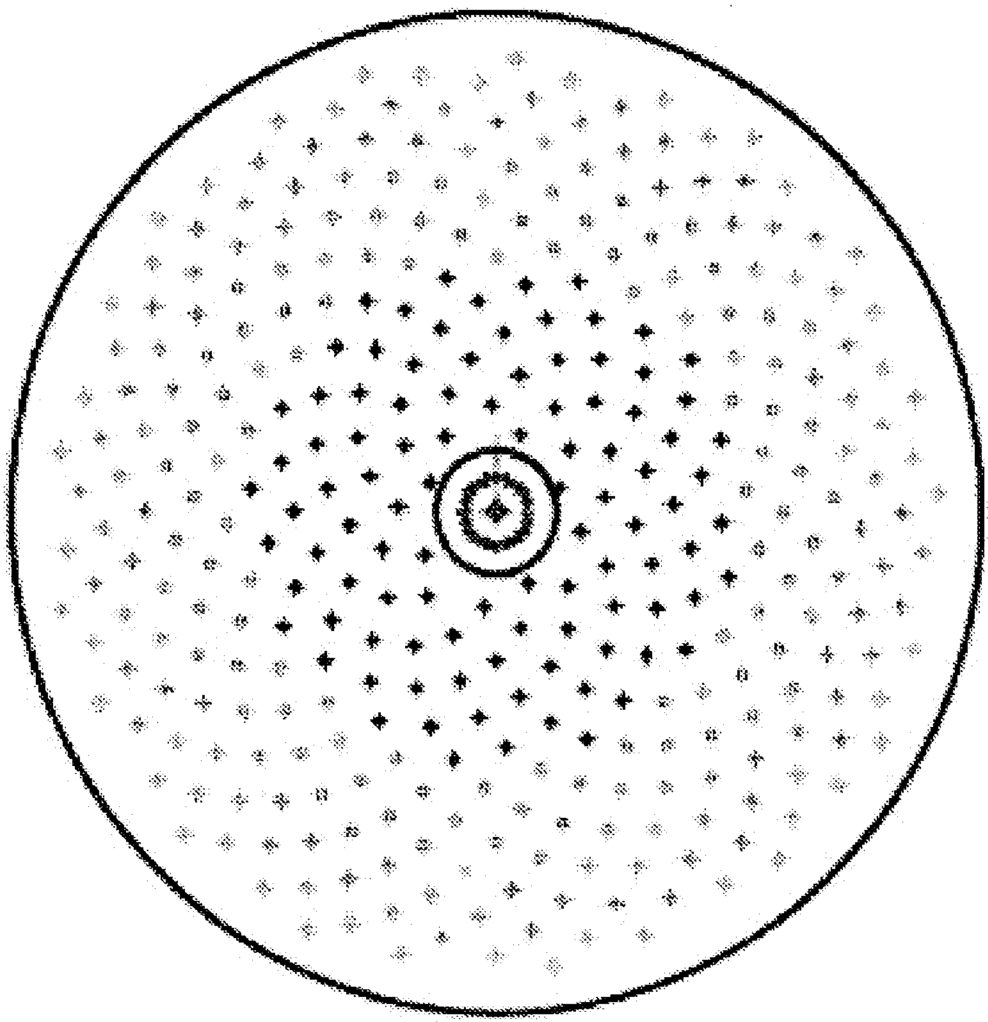

FIG. 18

FIG. 19

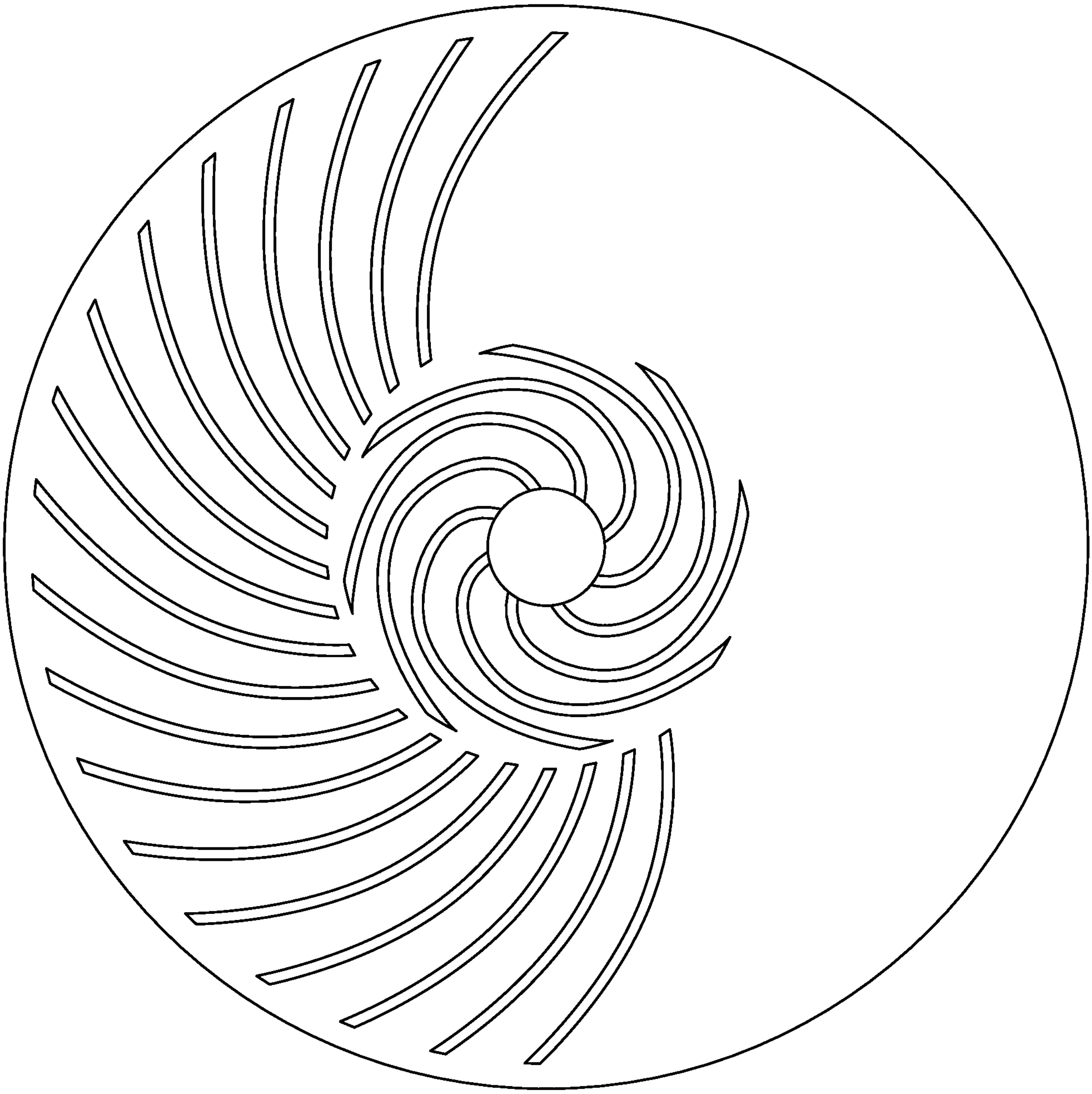

FIG. 20

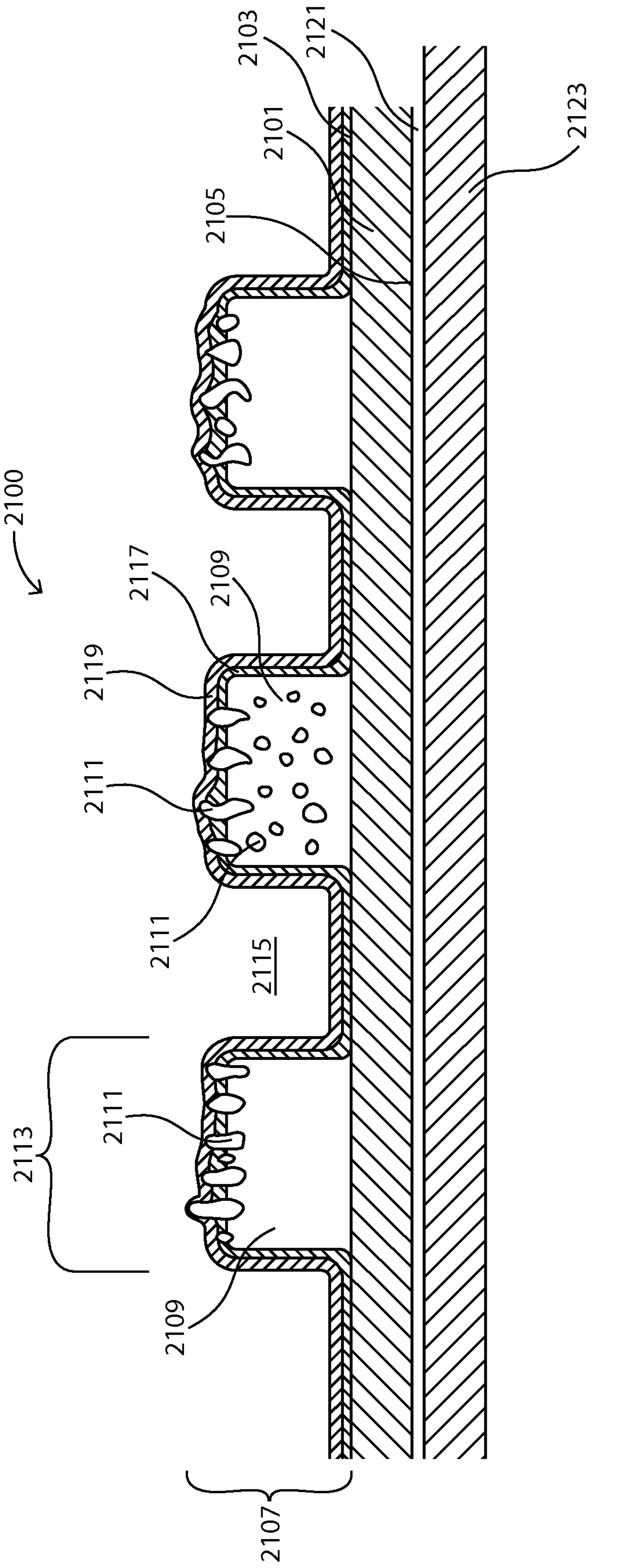
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FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/044591

A. CLASSIFICATION OF SUBJECT MATTER

B24D 7/00(2006.01)i, B24B 55/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B24D 7/00; B24B 7/00; B24D 11/04; C09K 3/14; B24D 18/00; B24B 1/00; B24D 11/00; B24B 55/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: abrasive, swarf, pattern, number

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009-0053982 A1 (POPOV, GEORGI M.) 26 February 2009 See paragraphs [0008]-[0009],[0014]-[0018] and figures 1-3.	1-15,31-45
A		16-30
A	US 7993419 B2 (HALL et al.) 09 August 2011 See column 5, line 14 - column 9, line 43 and figure 5.	1-45
A	US 2007-0243803 A1 (OKA et al.) 18 October 2007 See paragraphs [0038]-[0084] and figures 1-21.	1-45
A	US 2010-0003904 A1 (DUESCHER, WAYNE O.) 07 January 2010 See paragraphs [0189]-[0247] and figures 1-12.	1-45
A	US 6955587 B2 (GREGORY P. MULDOWNEY) 18 October 2005 See column 4, line 4 - column 9, line 31 and figures 2-4.	1-45

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"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)
"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
"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
"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
"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 October 2014 (31.10.2014)	**31 October 2014 (31.10.2014)**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2014/044591

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