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(71) Applicants:
- **Saint-Gobain Abrasives, Inc.**
Worcester, MA 01615-0008 (US)
- **Saint-Gobain Abrasifs**
78702 Conflans-Sainte-Honorine (FR)

(72) Inventors:
- **Huber, Cristophe**
78702 Conflans-Sainte-Honorine (FR)
- **Keijzer, Peter**
7151 HW Eibergen, Gelderland (NL)

(74) Representative: **Zimmermann & Partner**
Josephspitalstrasse 15
80331 München (DE)

(54) Method and apparatus for roll grinding

(57) In one aspect, a process for roll grinding employs a grinding wheel that is porous and permeable. In another aspect, a process for grinding mill rolls includes dressing the grinding wheel as the wheel traverses the surface of a mill roll. Other aspects relate to a system, e.g., a mill roll grinding machine, or parts thereof, in which a dressing tool contacts the wheel as the wheel grinds the surface of the mill roll. In specific examples, the wheel and a rotary dressing tool are maintained in contact as the wheel traverses the surface of the mill roll.

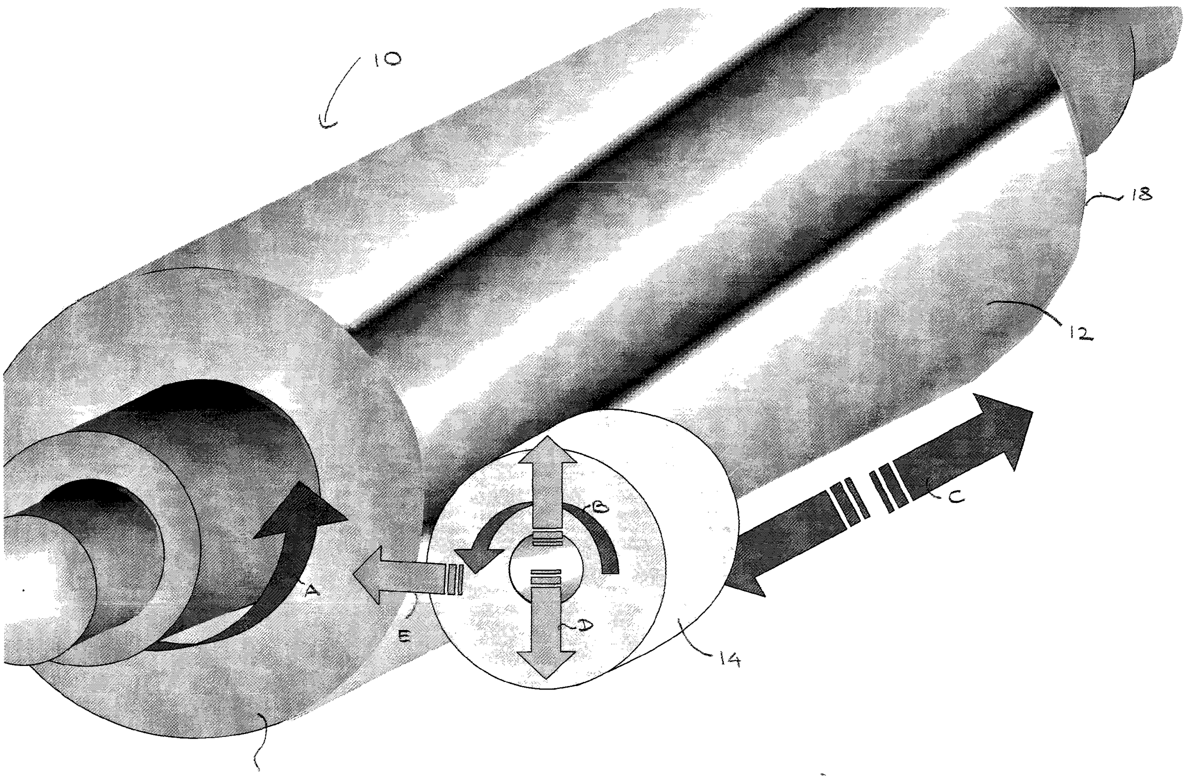

FIG. 1

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Description

BACKGROUND

[0001] Rolling refers to fabrication processes in which a material, e.g., a metal, is passed through at least one pair of rolls. Used in the surface finishing of metal sheets, mill rolls generally are large (e.g., 7 feet in length, 2 feet in diameter) metal rollers that can be made of forged steel, hard to grind high speed steel or ICDP steel with various Cr levels. The manufacture of these rolls often includes a cylindrical grinding process, known as (mill) roll grinding, in which a bonded abrasive wheel traverses the roll surface back and forth on a dedicated roll grinding machine, to grind and smooth the surface of the mill roll.

[0002] Some of the challenges presented by roll grinding processes relate to the surface finish of the roll. For instance, unstable grinding systems can cause the vibration amplitude between the grinding wheel and the workpiece to increase over time. This results in a series of undulations that develop and build along the surfaces of both the grinding wheel and workpiece, in a process known as regenerative or self-excited chatter and has been associated with imperfections (known as "chatter marks") in the surface of mill rolls following grinding. These chatter marks as well as other grinding patterns, feed lines, random marks, indentations, and other types of imperfections created on the roll surface during the grinding process are transferred onto the metal sheets being processed by the roll, compromising the quality of the final product.

[0003] Other challenges during mill roll grinding relate to the removal of bond material and worn abrasive grains accumulated during grinding. In many roll grinding operations, for example, dressing generally is performed when mounting a new wheel for the run out and opening the wheel surface prior to the first run. In addition, the wheel can be re-dressed after several passes of the wheel, using a stationary dressing tool that is outside the grinding zone. Since the grinding wheel must exit the grinding zone in order to be dressed, the roll grinding process is interrupted, increasing the overall time required to produce a finished roll.

SUMMARY

[0004] A need exists therefore for techniques and equipment that minimize or reduce the formation of chatter marks and other imperfections on the surface of mill rolls. A need also exists for roll grinding processes and systems that increase productivity and/or lower production costs associated with the manufacture of mill rolls.

[0005] These needs are satisfied by the independent claims 1, 14, and 15. Further advantageous featuring of the present invention are evident from the dependent claims, the description and the drawings.

[0006] One aspect of the invention relates to a method for mill roll grinding that employs a permeable grinding wheel.

[0007] In one embodiment, a process for grinding mill rolls includes mounting a grinding wheel on a mill roll grinding machine, the wheel comprising about 55% to about 80%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 4:1, preferably at least 5:1, abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain; b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll. The fibrous particles present in the wheel can be abrasive grain, filler, combinations thereof, or agglomerates thereof. The interconnected porosity provides an open structure of channels permitting passage of fluid, e.g., grinding coolant, or debris through the abrasive article during grinding.

[0008] In another embodiment, a process for grinding mill rolls includes: a) mounting a grinding wheel on a roll grinding machine, the wheel having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain; b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, while maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll. In specific examples, the wheel includes: (i) prior to curing the grinding wheel, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 4:1, preferably 5:1; (ii) after curing the grinding wheel, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding. The interconnected porosity present in the wheel provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding. The matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof

[0009] In a further embodiment, a process for grinding mill rolls includes: a) mounting grinding wheel on a roll grinding machine, the wheel comprising about 40% to about 54%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 4:1, preferably 5:1, abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.22 times the cross-sectional width of the abrasive grain; b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll. The interconnected porosity of the wheel provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding. The fibrous particles can be abrasive grain, filler, combinations thereof, and agglomerates thereof

[0010] In yet another embodiment, a process for grinding mill rolls includes: a) mounting a grinding wheel on a roll grinding machine, the wheel having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain; b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll. In specific examples the wheel includes: (i) prior to curing the abrasive article, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 4:1, preferably 5:1; (ii) after curing the abrasive article, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding. The interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding. The matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof.

[0011] In a further embodiment, a process for grinding mill rolls includes: a) mounting a grinding wheel on a roll grinding machine, the wheel comprising: a blend of abrasive grains including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0, or an agglomerate thereof; and ii) agglomerated abrasive grain granules including a plurality of abrasive grains held in a three-dimensional shape by a binding material; a bond; and at least about 35 volume percent porosity, b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll.

[0012] In still another embodiment, a process for grinding mill rolls includes: a) mounting a grinding wheel on a roll grinding machine, the wheel comprising: an agglomerate including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0; ii) a non-filamentary abrasive grain; and iii) a binding material, wherein the non-filamentary abrasive grain and filamentary sol-gel alumina abrasive grain are held in a three-dimensional shape by the binding material; a bond; and at least about 35 volume percent porosity; b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface; c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and d) grinding the surface of the mill roll.

[0013] Optionally, the process described above can further include dressing the grinding wheel. In some implementations, dressing is conducted while the wheel traverses the surface of the mill roll. Sequential dressing also can be employed.

[0014] Another aspect of the invention relates to a method of grinding mill rolls that includes continuous dressing of the abrasive wheel employed in the grinding operation.

[0015] In one embodiment, a process for grinding mill rolls comprises: mounting a grinding wheel on a roll grinding machine; bringing the wheel into contact with a rotating mill roll; traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; dressing the wheel as the wheel traverses across the surface of the mill roll; and grinding the surface of the mill roll.

[0016] In a further embodiment, a process for grinding a mill roll comprises moving a rotating grinding wheel together with a dressing tool along a length of a rotating mill roll, wherein the grinding wheel grinds a surface of the mill roll and the rotating grinding tool contacts a periphery of the grinding wheel.

[0017] In still another embodiment, the invention relates to a method for dressing a wheel grinding a mill roll. The method includes maintaining contact between the wheel and a rotary dressing tool as the wheel traverses a surface of the mill roll.

[0018] A further aspect of the invention relates to equipment used for grinding mill rolls.

[0019] In one embodiment, an apparatus for grinding mill rolls includes a first system for traversing a rotating grinding wheel across the surface of a mill roll maintaining continuous contact of the wheel with the mill roll; and a second system for maintaining continuous contact between the rotating grinding wheel traversing across the surface of the mill roll and a dressing tool, e.g., a dressing wheel.

[0020] In another embodiment, a roll grinding machine comprises an assembly for mounting a grinding wheel and a rotary dressing tool wherein the rotary dressing tool can contact a periphery of the grinding wheel, and means for moving the rotary dressing tool together with the grinding wheel, as the grinding wheel traverses a surface of a mill roll.

[0021] In a further embodiment, an apparatus for grinding mill rolls includes a dressing tool that is operationally linked to a grinding wheel to maintain contact between the dressing tool and the grinding wheel as the grinding wheel traverses a surface of the mill roll.

[0022] The invention can be practiced in the manufacture or reconditioning of rolls and has many advantages. Aspects of the invention provide versatile and flexible features that allow processing rolls made of many types of alloys and having convex, concave, bottleneck or other (complex) shapes. In many cases, practicing the invention results in higher G ratio (ratio of the volume of material removed from the workpiece to the volume of grinding wheel consumed during the process) and thus longer wheel life when compared to standard organic bonded wheels. In many of its implementations, the radial infeed can be increased significantly, thus reducing the number of passes required to produce a certain finish. Due to the high accuracy for each pass, less roll material needs to be removed, another feature that results in reduced processing times and also in finished workpieces that have longer roll life. Processing time also is reduced by using a dressing operation that does not interrupt grinding but that can be carried out continuously or as needed, without requiring the wheel to exit the grinding zone to be dressed by a stationary dressing tool.

[0023] The dressing system described herein can stabilize roll grinding, increasing the consistency of the process and some of the approaches described herein allow easy dressing and reshaping of the wheel. The speed ratio of the rotary dresser versus the wheel speed can be adjusted precisely, so that the wheel can be conditioned in very aggressive cutting action for rough grinding passes (or for first stands in mill) and also to obtain a smooth surface finish due to the reduced roughness of the wheel surface generated by the dressing system. The dressing arrangement and dressing operation described herein can be controlled by the CNC system of the roll grinding machine. In some implementations, the dressing tool can be profiled to avoid feed lines by breaking the edges of the grinding wheel.

[0024] Whereas vitrified wheels can raise burn problems, the highly porous and permeable wheels described herein provide improved coolant access thus reducing or minimizing heat generation. Aspects of the invention also contribute to increased cooling system life as less wheel debris and the metal chips are generated per unit time (longer wheel life for same material removal rate (MRR) and less roll material to remove to get to shape within tolerance).

[0025] Whereas when using conventional technology the surface quality of the roll typically is achieved by changing the grit size of the wheel, in some of its embodiments, the invention makes possible the control of surface quality of the roll through changing wheel speed and/or dressing parameters. In specific examples, the surface finish is controlled by the speed ratio of the wheel rather than the roll speed. In many of its implementations, the invention leads to better controlled surface finish, ranking from 0.2 microns up to 10 microns when using a vitrified grinding wheel.

[0026] Particularly, the present invention refers to process for grinding mill rolls, the process comprising:

a. mounting a grinding wheel on a roll grinding machine;
b. bringing the grinding wheel into contact with a rotating mill roll;
c. traversing the grinding wheel across a surface of the mill roll while maintaining continuous contact of the grinding wheel with the surface of the mill roll;
d. dressing the grinding wheel while the grinding wheel is in contact with the mill roll; and
e. grinding the surface of the mill roll.

[0027] Preferably, in the above process the grinding wheel is dressed with a rotary dressing tool.

[0028] Preferably, the dressing tool is rotated continuously.

[0029] Preferably, the dressing tool is rotated intermittently.

[0030] Preferably, the process can be under computer numerical control.

[0031] Preferably, the grinding wheel used in the above process includes a vitrified bond.

[0032] Specifically, the grinding wheel used in the above process comprises about 55% to about 80%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for roll grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof.

[0033] Particularly, the grinding wheel used in the above process can have an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprises: (i) prior to curing the grinding wheel, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the grinding wheel, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof.

[0034] Specifically, the grinding wheel used in the above process can comprise about 40% to about 54%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.22 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof.

[0035] Moreover, in the above process the grinding wheel can have an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprises: (i) prior to curing the abrasive article, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the abrasive article, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof.

[0036] In addition, the above process the wheel comprise:

a blend of abrasive grains including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0, or an agglomerate thereof; and ii) agglomerated abrasive grain granules including a plurality of abrasive grains held in a three-dimensional shape by a binding material;
a bond; and
at least about 35 volume percent porosity.

[0037] Alternatively, in the above process the wheel comprise:

an agglomerate including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0; ii) a non-filamentary abrasive grain; and iii) a binding material, wherein the non-filamentary abrasive grain and filamentary sol-gel alumina abrasive grain are held in a three-dimensional shape by the binding material;
a bond; and
at least about 35 volume percent porosity.

[0038] Furthermore, the present invention relates to process for grinding a mill roll, the process comprising:

moving a rotating grinding wheel together with a dressing tool along a length of a rotating mill roll, wherein the grinding wheel grinds a surface of the mill roll and the dressing tool contacts a periphery of the grinding wheel, as the wheel moves along the length of the rotating mill roll.

[0039] Moreover, the present invention also refers to method for dressing a wheel grinding a mill roll, the method comprising:

maintaining contact between the wheel and a rotary dressing tool as the wheel traverses a surface of the mill roll.

[0040] According to another aspect, the present invention relates to process for grinding mill rolls, including:

a) mounting a grinding wheel on a mill roll grinding machine, the wheel comprising about 55% to about 80%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof;
b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0041] Preferably, the process further comprises dressing the wheel, whereby more preferred the wheel is dressed during step (c)

[0042] According to still another aspect, the present invention refers to process for grinding mill rolls, the process comprising:

a) mounting a grinding wheel on a roll grinding machine, the wheel having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprising: (i) prior to curing the grinding wheel, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the grinding wheel, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof;
b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0043] Preferably, the process further comprises dressing the wheel, whereby more preferred the wheel is dressed during step (c)
[0044] According to still another aspect, the present invention relates to process for grinding mill rolls, the process comprising:

a) mounting grinding wheel on a roll grinding machine, the wheel comprising about 40% to about 54%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.22 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof;
b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0045] Preferably, the process comprises dressing the wheel, whereby more preferred the wheel is dressed during step (c).
[0046] According to still another aspect, the present invention refers to process for grinding mill rolls, the process comprising:

a) mounting a grinding wheel on a roll grinding machine, the wheel having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprising: (i) prior to curing the abrasive article, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the abrasive article, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof;
b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0047] Preferably, the process comprises dressing the wheel, whereby more preferred the wheel is dressed during step (c).
[0048] According to a still further aspect, the present invention refers to a process for grinding mill rolls, the process comprising:

a) mounting a grinding wheel on a roll grinding machine, the wheel comprising: a blend of abrasive grains including:

i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0, or an agglomerate thereof; and ii) agglomerated abrasive grain granules including a plurality of abrasive grains held in a three-dimensional shape by a binding material; a bond; and at least about 35 volume percent porosity;
b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0049] Preferably, comprises dressing the wheel, whereby more preferred the wheel is dressed during step (c).
[0050] According to still another preferred aspects the present invention relates to process for grinding mill rolls, the process comprising:

a) mounting a grinding wheel on a roll grinding machine, the wheel comprising:

an agglomerate including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0; ii) a non-filamentary abrasive grain; and iii) a binding material, wherein the non-filamentary abrasive grain and filamentary sol-gel alumina abrasive grain are held in a three-dimensional shape by the binding material; a bond; and at least about 35 volume percent porosity;

b) bringing the wheel into contact with a rotating mill roll having a cylindrical surface;
c) traversing the wheel across the surface of the mill roll, maintaining continuous contact of the wheel with the surface of the mill roll; and
d) grinding the surface of the mill roll.

[0051] Preferably, comprises dressing the wheel, whereby even more preferred the wheel is dressed during step (c).
[0052] According to a further aspect, the present invention refers to roll grinding machine comprising an assembly for mounting a grinding wheel and a rotary dressing tool wherein the rotary dressing tool can contact a periphery of the grinding wheel, and means for moving the rotary dressing tool together with the grinding wheel, as the grinding wheel traverses a surface of a mill roll.
[0053] Moreover, according to another aspect, the present invention relates to apparatus for grinding mill rolls including a first system for traversing a rotating grinding wheel across the surface of a mill roll maintaining contact of the grinding wheel with the mill roll; and a second system for maintaining contact between the rotating grinding wheel traversing across the surface of the mill roll and a rotating dressing tool.
[0054] Preferably, the first system and the second system of the apparatus are under CNC control.
[0055] In addition, the present invention refers to an apparatus for grinding mill rolls, which apparatus includes a dressing tool that is operationally linked to a grinding wheel to maintain contact between the dressing tool and the grinding wheel as the grinding wheel traverses a surface of the mill roll.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] In the accompanying drawings, reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the principles of the invention. Of the drawings:
[0057] FIG. 1 is a view of a roll and grinding wheel arrangement that can be used during mill roll grinding.
[0058] FIG. 2 is a view of a system for mill roll grinding including a roll, a grinding wheel and a stationary dressing stick.
[0059] FIG. 3 is a view of a system for mill roll grinding including a roll, a grinding wheel and a stationary diamond dressing system.
[0060] FIGS. 4A and 4B are views of a system for mill roll grinding including a roll, a grinding wheel and a stationary rotating dressing roll.
[0061] FIGS 5A and 5B are views of a system for mill roll grinding including an arrangement that employs a non-stationary rotating dressing roll that is in contact with the grinding wheel as the grinding wheel traverses the roll.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0062] The invention generally relates to grinding mill rolls. In its various embodiments it can be practiced in the manufacture or reconditioning of rolls made of different materials and having different shapes, in hot, cold as well as pickled and cold roll applications. Examples of roll materials that can be processed using aspects of the invention include but are not limited to cast steel, forged steel, high speed (HSS) steel, cast HSS steel, high chromium (Cr) steel, 5% Cr and low Cr steel, indefinite chill double pour (ICDP) steel, cast ICDP steel and so forth.

[0063] Aspects of the invention can be practiced in grinding rolls designed for the production of slabs, plates, large diameter pipe, skelp, pipe and tubing, strip, tin plate, blooms, billets, structural shapes, rails, tube rounds, seamless pipe, wire rods, wire, bars, cold drawn bars and other metal articles. The rolls can be cylindrical, convex, concave, bottleneck, or can have other complex shapes.

[0064] Generally roll grinding is carried out using machines designed for such operations. In specific examples of the invention, the machine employed is numerically controlled, preferably computer numerically controlled (CNC). Suitable roll grinding machines may be obtained from Herkules, Meuselwitz, Germany, Waldrich Siegen, Burbach, Germany, and Pomini (Techint Company), Milan, Italy, Naxos Union, Germany and from various other equipment manufacturers who supply equipment to the roll grinding industry.

[0065] During roll grinding, a selected grinding wheel is mounted on a roll grinding machine in an arrangement that allows grinding the surface of the roll. Shown in FIG. 1, for example, is arrangement 10 which includes roll 12, being rotated in the direction indicated by arrow A, and grinding wheel 14, rotated in the direction indicated by arrow B. Once rotating grinding wheel 14 is brought into contact with the rotating roll, the wheel is gradually traversed across the surface of the rotating roll, between ends 16 and 18 of the roll, as indicated by arrow C, to remove material from the roll surface. In an illustrative example, roll 12 has a roll length of 1880 millimeters (mm) and a roll diameter of 790 mm; the dimensions of wheel 14 are 915 mm x 102 mm x 304.8 mm with a wheel stub of about 550 mm.

[0066] Roll 12 is rotated (arrow A) at a roll speed Vr, which can be within the range of from about 20 rotations per minute (RPM) to about 60 RPM, e.g., 40 RPM. The wheel motion combines the wheel speed, Vs, (arrow B) and the wheel oscillation, O, illustrated in FIG. 1 by arrow D. In many cases Vs is within the range of from about 12 to about 50 m/s, preferably at a speed within the range of from about 30 to about 35 m/s. The wheel oscillation can be, for example, about +/- 10% of Vs.

[0067] Traversal of the grinding wheel (arrow C) is carried out at a traverse speed Vf which typically is within the range of from about 200 millimeters per minute (mm/min) to about 4000 mm/min, for instance about 2000 mm/min. On a typical roll measuring 7 feet in length and 2 feet in diameter the traversal step may take about 0.6 to 1.0 minutes to complete.

[0068] Also of interest are parameters that describe the constant infeed Ac (typically in micrometers per minute (μm/min) and the sequential infeed (μm) that takes place at each end of a roll. These are illustrated by arrow E.

[0069] In a specific embodiment of the invention, grinding wheel 14 is an abrasive wheel described in U.S. Patent No. 5,738,697, with the title *High Permeability Grinding Wheels,* issued on April 14, 1998 to Wu, et al., the teachings of which are incorporated herein by reference in their entirety.

[0070] In one example grinding wheel 14 comprises about 55% to about 80%, by volume, interconnected porosity, abrasive grain and bond in amounts effective for grinding, and has an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding.

[0071] In another example grinding wheel 14 comprises about 40% to about 54%, by volume, interconnected porosity, abrasive grain and bond in amounts effective for grinding, and has an air permeability measured in cc air/second/inch of water of at least 0.22 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding.

[0072] The grinding wheel preferably contains a vitrified bond and fibrous particles of abrasive grain having a L/D ratio of at least 4:1, for example 5:1 or more. The abrasive grain may be a sintered seeded sol gel alumina filamentary grain and the wheel may be made with or without added pore inducer. The fibrous filler material may be used, alone or in combination with fibrous abrasive grain, to create interconnected porosity in the abrasive article.

[0073] The wheel includes effective amounts of abrasive grain and bond needed for roll grinding operations and, optionally, fillers, lubricants or other components. It preferably contains the maximum volume of permeable porosity which can be achieved while retaining sufficient structural strength to withstand grinding forces. For example, the grinding wheel may comprise about 40 to 80%, preferably 55 to 80% and most preferably 60 to 70%, by volume, interconnected porosity. As used herein, the term "interconnected porosity" refers to the porosity of the abrasive tool that consists of the interstices between particles of bonded abrasive grain which are open to the flow of a fluid.

[0074] The balance of the volume, 20 to 60%, is abrasive grain and bond in a ratio of about 20:1 1 to 1:1 grain to bond. These amounts are effective for grinding, with higher amounts of bond and grain required for larger abrasive wheels and for formulations containing organic bonds rather than vitrified bonds. Relative to conventional abrasive grain, superabrasive grain in vitrified bond typically include a higher bond content. In one implementation, the grinding wheel is formed using a vitrified bond and contain about 15 to 43% abrasive grain and 3 to 15% bond.

[0075] As used herein, the permeability of the grinding wheel is Q/P, where Q means flow rate expressed as cc of air flow, and P means differential pressure. Q/P is the pressure differential measured between the abrasive tool structure and the atmosphere at a given flow rate of a fluid (e.g., air). This relative permeability Q/P is proportional to the product of the pore volume and the square of the pore size. Larger pore sizes are preferred. Pore geometry and abrasive grain size or grit are other factors affecting Q/P, with larger grit size yielding higher relative permeability.

[0076] The relationship between permeability and grit size for 55% to 80% porosity may be expressed by the following equation:

$$\text{minimum permeability} = 0.44 \text{ X cross-sectional width of the abrasive grain.}$$

[0077] A cross-sectional width of at least 220 grit (70 micrometers) is preferred.

[0078] Q/P can be measured using permeability testing based on D'Arcy's Law which governs the relationship between the flow rate and pressure on porous media. A suitable apparatus includes an air supply, a flowmeter (to measure Q, the inlet air flow rate), a pressure gauge (to measure change in pressure at various wheel locations) and a nozzle connected to the air supply for directing the air flow against various surface locations on the wheel.

[0079] For an abrasive tool having about 55% to 80% porosity in a vitrified bond, using an abrasive grain grit size of 80 to 120 grit (132-194 micrometers) in cross-sectional width, a preferred air permeability is at least 40 cc/second/inch of water. For an abrasive grain grit size greater than 80 grit (194 micrometers), a preferred permeability is at least 50 cc/second/inch of water.

[0080] For an abrasive tool having from about 40% to less than about 55% porosity in a vitrified bond, using an abrasive grain size of 80 to 120 grit (132-194 micrometers), an air permeability of at least 29 cc/second/inch of water is preferred. For an abrasive grit size greater than 80 grit (194 micrometers), the minimum permeability is at least 42 cc/second/inch of water is required.

[0081] The relationship between permeability and grit size for from about 40% to less than 55% porosity may be expressed by the following equation:

$$\text{minimum permeability} = 0.22\text{.times.cross-sectional width of the abrasive grain.}$$

[0082] Similar relative permeability limits for other grit sizes, bond types and porosity levels may be determined by the practitioner by applying these relationships and D'Arcy's Law to empirical data for a given type of abrasive article.

[0083] Smaller cross-sectional width grain may require the use of filament spacers (e.g., bubble alumina) to maintain permeability during molding and firing steps. Larger grit sizes can be used. Generally, grit sizes are selected based on the nature of the workpiece, in this case the mill roll, the grinding machine used, wheel composition and geometry, surface finish and other, variable elements which can be selected and implemented by the practitioner in accordance with the requirements of a particular grinding operation.

[0084] The grinding wheel described above has a unique and stable interconnecting porosity defined by a matrix of fibrous particles ("the fibers"). The fibers may comprise, consist essentially of or consist of abrasive grain or filler or a combination of the two and may have a variety of shapes and geometric forms. The fibers may be mixed with the bond components and other abrasive tool components, then pressed and cured or fired to form the wheel. In another preferred embodiment, a mat of fibers, and optionally, other tool components is preformed and, optionally, infused with other mix components, then cured or fired to make the tool in one or more steps.

[0085] If the fibers are arranged even more loosely by adding closed cell or organic pore inducer to further separate particles, even higher permeabilities can be achieved. Upon firing, an article comprised of the organic particles will shrink back to result in an article having a smaller dimension because the fibers have to interconnect for integrity of the article. The final dimension after firing of the abrasive tool and the resultant permeability created is a function of aspect ratio of fibers. The higher the L/D is, the higher the permeability of a packed array will remain.

[0086] Any abrasive mix formulation may be used to prepare grinding wheel 14, provided the mix, after forming the article and firing it, yields an article having the minimum permeability and interconnected porosity characteristics discussed.

[0087] In a preferred embodiment, wheel 14 comprises a filamentary abrasive grain particle incorporating sintered sol gel alpha alumina based polycrystalline abrasive material, preferably having crystallites that are no larger than 1-2 microns, more preferably less than 0.4 microns in size. Suitable filamentary grain particles are described in U.S. Pat. Nos. 5,244,477 to Rue, et al.; 5,129,919 to Kalinowski, et al.; 5,035,723 to Kalinowski, et al.; and 5,009,676 to Rue, et al., which are hereby incorporated by reference. Other types of polycrystalline alumina abrasive grain having larger crystallites from which filamentary abrasive grain may be obtained and used herein are disclosed in, e.g., U.S. Pat. Nos. 4,314,705 to Leitheiser, et al.; and 5,431,705 to Wood, which are hereby incorporated by reference. Filamentary grain can have a L/D aspect ratio of at least 4:1, preferably at least 5:1. Various filamentary shapes may be used, including, e.g., straight, curved, corkscrew and bent fibers. In a specific example, the alumina fibers are hollow shapes.

[0088] In a preferred implementation the filamentary abrasive grain particles have a grit size greater than 220 grit (i.e., a particle size of greater than 79 microns in diameter). In the alternative, filamentary abrasive grain particles having a grit size of 400 to 220 grit (23 to 79 micrometers) may be used in an agglomerated form having an average agglomerated particle diameter of greater than 79 μm. In a second alternative preferred embodiment, filamentary abrasive grain particles having a grit size of 400 to 220 grit may be used with pore inducer (organic material or closed cell) in an amount effective to space the filaments during firing, and thereby maintain a minimum permeability of at least about 40 cc/ second/inch water in the finished wheel.

[0089] Examples of abrasive grains that can be used in the grinding wheel, whether or not in filamentary form, include but are not limited to conventional abrasives, such as, for instance, aluminum oxide, silicon carbide, zirconia-alumina, garnet and emery may be used in a grit size of about 0.5 to 5,000 micrometers, preferably about 2 to 200 micrometers. Superabrasives, including, but not limited to, diamond, cubic boron nitride and boron suboxide (as described in U.S. Pat. No. 5,135,892, which is hereby incorporated by reference) may be utilized, e.g., in the same grit sizes as conventional abrasive grain.

[0090] While any bond normally used in abrasive articles may be employed with the fibrous particles to form a bonded abrasive article, a vitrified bond is preferred for structural strength. Other bonds known in the art, such as organic or resinous bonds, together with appropriate curing agents, also may be used. e.g., to form articles having an interconnected porosity of about 40 to 80%.

[0091] The grinding wheel can include additives, such as fillers, preferably as filamentary or matted or agglomerated filamentary particles, pore inducers, lubricants and processing adjuncts, such as antistatic agents and temporary binding materials for molding and pressing the articles. As used herein, "fillers" excludes pore inducers of the closed cell and organic material types. The appropriate amounts of these optional abrasive mix components can be readily determined by those skilled in the art.

[0092] Suitable fillers include secondary abrasives, solid lubricants, metal powder or particles, ceramic powders, such as silicon carbides, and other fillers known in the art.

[0093] The grinding wheel can be formed using conventional techniques and equipment. Cold, warm or hot pressing can be employed and the wheel can be fired by conventional firing processes known in the art and selected for the type and quantity of bond and other components. In general, as the porosity content increases, the firing time and temperature decreases.

[0094] Examples of techniques that can be employed to make the grinding wheel are described in U.S. Patent No. 5,738,696, with the title *Method for Making High Permeable Grinding Wheels,* issued to Wu on April 14, 1998, the teachings of which are incorporated herein by reference in their entirety. In addition, the grinding wheel can be prepared by one step methods, such as is disclosed in U.S. Pat. No. 5,221,294, titiled *Process for Producing Self-Bonded Ceramic Abrasive Wheels,* issued to Carman, et al. on June 24, 1993, which is hereby incorporated by reference. When using a one step method, a porous structure is initially obtained by selecting a mat or foam structure having interconnected porosity and consisting of an organic (e.g., polyester) or inorganic (e.g., glass) fiber or ceramic fiber matrix, or a ceramic or glass or organic honeycomb matrix or a combination thereof and then infiltrating the matrix with abrasive grain, and bond, followed by firing and finishing, as needed, to form the abrasive article. In a preferred embodiment, layers of polyester fiber mats are arranged in the general shape of an abrasive wheel and infiltrated with an alumina slurry to coat the fibers. This construction can be heated to about 1510 degrees centigrade (°C) for about one hour to sinter the alumina and thermally decompose the polyester fiber, and then further processed (e.g., infiltrated with other components) and fired to form the abrasive article. Suitable fiber matrices include a polyester nylon fiber mat product obtained from Saint-Gobain Corporation, Worcester, Mass.

[0095] Woven mats of resin coated fiberglass that are layered into an abrasive wheel mold along with an abrasive mix containing abrasive grain, vitrified bond components and optional components also can be utilized. Such a structured mix can be processed with conventional methods to form an abrasive article having regularly spaced pores in the shape of large channels transversing the wheel.

[0096] In another specific embodiment of the invention, grinding wheel 14 is an abrasive wheel having a permeable structure such as described by Xavier Orlhac et al. in U.S. Patent Application Publication No. 2007/0074456 A1, titled *Abrasive Tools Having a Permeable Structure*, published on April 5, 2007, the teachings of which are incorporated herein by reference in their entirety. This tool has at least about 35% porosity, preferably about 35% to about 80% porosity by volume of the tool. In one implementation, at least about 30% by volume of the total porosity is interconnected porosity. The existence of interconnected porosity is typically confirmed by measuring the permeability of the abrasive tool to the flow of air or water under controlled conditions, such as in the test methods disclosed in U.S. Pat. Nos. 5,738,696 and 5,738,697, discussed above.

[0097] The term "filamentary" abrasive grain is used to refer to filamentary ceramic abrasive grain having a generally consistent cross-section along its length, where the length is greater than the maximum dimension of the cross-section. The maximum cross-sectional dimension can be as high as about 2 mm, preferably below about 1 mm, more preferably below about 0.5 mm. The filamentary abrasive grain may be straight, bent, curved or twisted so that the length is measured along the body rather than necessarily in a straight line. Preferably, the filamentary abrasive grain is curved or twisted.

[0098] The filamentary abrasive grain used in this implementation of wheel 14 has an aspect ratio of greater than 1.0, preferably at least 2:1, and most preferably at least about 4:1, for example, at least about 7:1 and in a range of between about 5:1 and about 25:1. The term "aspect ratio" or the "length-to-cross-sectional-width-aspect ratio" refers to the ratio between the length along the principal or longer dimension and the greatest extent of the grain along any dimension perpendicular to the principal dimension. Where the cross-section is other than round, e.g., polygonal, the longest measurement perpendicular to the lengthwise direction is used in determining the aspect ratio.

[0099] The term "agglomerated abrasive grain granules" or "agglomerated grain" refers to three-dimensional granules comprising abrasive grain and a binding material, the granules having at least 35 volume % porosity. Unless filamentary grains are described as making up all or part of the grain in the granules, the agglomerated abrasive grain granules consist of blocky or sphere-shaped abrasive grain having an aspect ratio of about 1.0. The agglomerated abrasive grain granules are exemplified by the agglomerates described in U.S. Pat. No. 6,679,758 B2, titled *Porous Abrasive Articles with Agglomerated Abrasives*, issued to Bright et al. on January 20, 2004. In this embodiment, wheel 14 is made with grain blends comprising filamentary abrasive grain, either in loose form and/or in agglomerated form, together with agglomerated abrasive grain granules comprising blocky or sphere-shaped abrasive grain having an aspect ratio of about 1.0. In another example, the wheel is made with agglomerated filamentary abrasive grain granules containing blocky or sphere-shaped abrasive grain having an aspect ratio of about 1.0. Each of these wheels optionally may include in the grain blend one or more secondary abrasive grains in loose form.

[0100] In one implementation, the blend comprises the filamentary sol-gel alumina abrasive grain and agglomerated abrasive grain granules. The blend can include about 5-90%, preferably about 25-90%, more preferably about 45-80%, by weight of the filamentary sol-gel alumina abrasive grain with respect to the total weight of the blend. The blend can further include about 5-90%, preferably about 25-90%, more preferably about 45-80%, by weight, of the agglomerated abrasive grain granules. The blend optionally contains a maximum of about 50%, preferably about 25%, by weight of secondary abrasive grain that is neither the filamentary grain, nor the agglomerated grain. The selected quantities of the filamentary grain, the agglomerated grain and the optional secondary abrasive grain total 100%, by weight, of the total grain blend used in the abrasive tools of the invention. Suitable secondary abrasive grains for optionally blending with the filamentary grain and the agglomerated grain are described below.

[0101] In another implementation, the blend includes an agglomerate of the filamentary sol-gel alumina abrasive grain and the agglomerated abrasive grain granules. The agglomerate of the filamentary sol-gel alumina abrasive grain comprises a plurality of grains of the filamentary sol-gel alumina abrasive grain and a second binding material. The filamentary sol-gel alumina abrasive grains are held in a three-dimensional shape by the second binding material.

[0102] Optionally, the agglomerate of the filamentary sol-gel alumina abrasive grain further comprises a secondary abrasive grain. The secondary abrasive grain and filamentary abrasive grain are held in a three-dimensional shape by the second binding material. The secondary abrasive grain can include one or more of the abrasive grains known in the art for use in abrasive tools, such as the alumina grains, including fused alumina, non-filamentary sintered sol-gel alumina, sintered bauxite, and the like, silicon carbide, alumina-zirconia, aluminoxynitride, ceria, boron suboxide, garnet, flint, diamond, including natural and synthetic diamond, cubic boron nitride (CBN), and combinations thereof. Except when sintered sol-gel alumina is used, the secondary abrasive grain can be any shape, including filament-type shapes. Preferably, the secondary abrasive grain is a non-filamentary abrasive grain.

[0103] The amounts of the filamentary abrasive grain in the agglomerate of the filamentary abrasive grain can be in a range of about 15-95%, preferably about 35-80%, more preferably about 45-75%, by weight with respect to the total weight of the agglomerate.

[0104] The amount of the secondary abrasive grains in the agglomerate of the filamentary abrasive grain is typically in a range of about 5-85%, preferably about 5-65%, more preferably about 10-55%, by weight with respect to the total weight of the agglomerate. As in the case of blends of filamentary grain and agglomerated grain, optional secondary grain may be added to the agglomerated filamentary grain to form the total grain blend used in the abrasive tools of the invention. Once again, a maximum of about 50%, preferably about 25%, by weight, of the optional secondary abrasive grain may be blended with the filamentary grain agglomerate to arrive at the total grain blend used in the abrasive tools.

[0105] The filamentary sol-gel alumina abrasive grain includes polycrystals of sintered sol-gel alumina. Seeded or unseeded sol-gel alumina can be included in the filamentary sol-gel alumina abrasive grain. Preferably, a filamentary, seeded sol-gel alumina abrasive grain is used for the blend of abrasive grains. In a specific embodiment, the sintered sol-gel alumina abrasive grain includes predominantly alpha alumina crystals having a size of less than about 2 microns, more preferably no larger than about 1-2 microns, even more preferably less than about 0.4 microns.

[0106] Sol-gel alumina abrasive grains can be made by the methods known in the art (see, for example, U.S. Pat. Nos. 4,623,364; 4,314,827; 4,744,802; 4,898,597; 4,543,107; 4,770,671; 4,881,951; 5,011,508; 5,213,591; 5,383,945; 5,395,407; and 6,083,622, the contents of which are hereby incorporated by reference). In many cases, these grains are made by forming a hydrated alumina gel which may also contain varying amounts of one or more oxide modifiers (e.g., MgO, ZrO_2 or rare-earth metal oxides), or seed/nucleating materials (e.g. α-Al_2O_3, β-Al_2O_3, γ-Al_2O_3, α-Fe_2O_3 or chromium oxides), and then drying and sintering the gel (see for example, U.S. Pat. No. 4,623,364).

[0107] Typically, the filamentary sol-gel alumina abrasive grain can be obtained by a variety of methods, such as by extruding or spinning a sol or gel of hydrated alumina into continuous filamentary grains, drying the filamentary grains so obtained, cutting or breaking the filamentary grains to the desired lengths and then firing the filamentary grains to a temperature of, preferably not more then about 1500° C. Preferred methods for making the grain are described in U.S. Pat. No. 5,244,477, U.S. Pat. No. 5,194,072 and U.S. Pat. No. 5,372,620. Extrusion is most useful for sol or gel of hydrated alumina between about 0.254 mm and about 1.0 mm in diameter which, after drying and firing, are roughly equivalent in diameter to that of the screen openings used for 100 grit to 24 grit abrasives, respectively. Spinning is most useful for filamentary grains sized less than about 100 microns in diameter after firing.

[0108] Gels most suitable for extrusion generally have a solid-content of about 30-68%. The optimum solid-content varies with the diameter of the filament being extruded. For example, an about 60% solid-content is preferred for filamentary abrasive grains having a fired diameter roughly equivalent to the screen opening for a 50-grit crushed abrasive grain. If the filamentary sol-gel alumina abrasive grains are formed by spinning, it is desirable to add about 1% to 5% of a non-glass-forming spinning aid, such as polyethylene oxide, to the sol from which the gel is formed in order to impart desirable viscosity and elastic properties to the gel for the formation of filamentary abrasive grains. The spinning aid is burnt out of the filamentary abrasive grains during calcining or firing.

[0109] When a filamentary, seeded sol-gel alumina abrasive grain is used for the blend of abrasive grains, during the process of extruding or spinning a sol or gel of hydrated alumina into continuous filamentary grains, an effective amount of a submicron crystalline seed material that promotes a rapid conversion of the hydrated alumina in the gel to very fine alpha alumina crystals is preferably added. Examples of the seed material are as described above.

[0110] Various desired shapes can be generated for extruded gel grains by extruding the gel through dies having the shape desired for the cross section of the grains. These can be, for example, square, diamond, oval, tubular, or star-shaped. In general, however, the cross section is round. The initially formed continuous filamentary grains are preferably broken or cut into lengths of the maximum dimension desired for the intended grinding application. After the filamentary gel grains have been shaped as desired, cut or crushed, and dried if needed, they are converted into a final form of abrasive grains by controlled firing. Generally, a temperature for the firing step is in a range of between about 1200°C and about 1350°C. Typically, firing time is in a range of between about 5 minutes and 1 hour. However, other temperatures and times may also be used. For grains coarser than about 0.25 mm, it is preferred to prefire the dried material at about 400-600°C from about several hours to about 10 minutes in order to remove the remaining volatiles and bound water which might cause cracking of the grains during firing. Particularly for grains formed from seeded gels, excessive firing quickly causes larger grains to absorb most of all of smaller grains abound them, thereby decreasing the uniformity of the product on a micro-structural scale.

[0111] Agglomerated abrasive grain granules for the blend of abrasive grains in the present invention are three-dimensional granules that include a plurality of abrasive grains and a binding material. The agglomerated abrasive grain granules have an average dimension that is about 2 to 20 times larger than the average grit size of the abrasive grains. Preferably, the agglomerated abrasive grain granules have an average diameter in a range of between about 200 and about 3000 micrometers. Typically, the agglomerated abrasive grain granules have a loose packing density (LPD) of, e.g., about 1.6 g/cc for 120 grit size (106 microns) grain and about 1.2 g/cc for 60 grit (250 microns) size grain, and a porosity of about 30 to 88%, by volume. Agglomerated filamentary abrasive grain granules made with TG2 grain have a loose packing density of about 1.0 g/cc. For most grains, the loose packing density of the agglomerated abrasive grain is approximately 0.4 times the loose packing density of the same grain measured as loose, unagglomerated grain. The agglomerated abrasive grain granules preferably have a minimum crush strength value of about 0.2 MPa.

[0112] The agglomerated abrasive grain granules may include one or more of the abrasive grains known to be suitable for use in abrasive tools, such as the alumina grains, including fused alumina, non-filamentary sol-gel sintered alumina, sintered bauxite, and the like; silicon carbide; alumina-zirconia, including cofused alumina-zirconia and sintered alumina-zirconia; aluminum oxynitride; boron suboxide; garnet; flint; diamond, including natural and synthetic diamond; cubic boron nitride (CBN); and combinations thereof. Additional examples of suitable abrasive grains include unseeded, sintered sol-gel alumina abrasive grains that include microcrystalline alpha-alumina and at least one oxide modifier, such as rare-earth metal oxides (e.g., CeO_2, Dy_2O_3, Er_2O_3, Eu_2O_3, La_2O_3, Nd_2O_3, Pr_2O_3, Sm_2O_3, Yb_2O_3, and Gd_2O_3, alkali metal oxides (e.g., Li_2O, Na_2O and K_2O), alkaline-earth metal oxides (e.g., MgO, CaO, SrO and BaO) and transition metal oxides (e.g., HfO_2, Fe_2O_3, MnO, NiO, TiO_2, Y_2O_3, ZnO and ZrO_2) (see, for example, U.S. Pat. Nos. 5,779,743, 4,314,827, 4,770,671, 4881,951, 5429,647 and 5,551,963, the entire teachings of which are incorporated herein by reference). Specific examples of the unseeded, sintered sol-gel alumina abrasive grains include rare-earth aluminates represented by the formula of $LnMAl_{11}O_{19}$, wherein Ln is a trivalent metal ion such as La, Nd, Ce, Pr, Sm, Gd, or Eu, and M is a divalent metal cation such as Mg, Mn, Ni, Zn, Fe, or Co (see, for example, U.S. Pat. No. 5,779,743). Such rare-earth aluminates generally have a hexagonal crystal structure, sometimes referred to as a magnetoplumbite crystal structure. A variety of examples of agglomerated abrasive grain granules can be found in U.S. Pat. No. 6,679,758 B2 and U.S. Patent Application Publication No. 2003/0194954, the entire teachings of which are incorporated herein by reference.

[0113] Any size or shape of abrasive grain may be used. Preferably, the size of the agglomerated abrasive grain granules for the blend of abrasive grains is chosen to minimize the loss in wheel porosity and permeability. Grain sizes suitable for use in the agglomerated abrasive grain granules range from regular abrasive grits (e.g., greater than about 60 and up to about 7,000 microns) to microabrasive grits (e.g., about 0.5 to about 60 microns), and mixtures of these sizes. For a given abrasive grinding operation, it may be desirable to agglomerate abrasive grains with a grit size smaller than an abrasive grain (non-agglomerated) grit size normally selected for this abrasive grinding operation. For example, agglomerated 80 grit size (180 microns) abrasive may be substituted for 54 grit (300 microns) abrasive, agglomerated 100 grit (125 microns) for 60 grit (250 microns) abrasive and agglomerated 120 grit (106 microns) for 80 grit (180 microns) abrasive.

[0114] A preferred agglomerate size for typical abrasive grains ranges from about 200 to about 3,000, more preferably about 350 to about 2,000, most preferably about 425 to about 1,000 micrometers in average diameter. For microabrasive grain, a preferred agglomerate size ranges from about 5 to about 180, more preferably about 20 to about 150, most preferably about 70 to about 120 micrometers in average diameter.

[0115] In the agglomerated abrasive grain granules for the invention, abrasive grains are typically present at about 10 to about 95 volume % of the agglomerate. Preferably, abrasive grains are present at about 35 to about 95 volume %, more preferably about 48 to about 85 volume %, of the agglomerate. The balance of the agglomerate comprises binder material and pores.

[0116] As with the agglomerated abrasive grain granules, an agglomerate of the filamentary sol-gel abrasive grains are three-dimensional granules that include a plurality of filamentary sol-gel abrasive grains and a second binding material. Preferably, the agglomerate of the filamentary sol-gel abrasive grains further includes a secondary abrasive grain as described above. In one specific example, the secondary abrasive grain is non-filamentary in shape. In one embodiment, the agglomerate of the filamentary sol-gel abrasive grain that includes a plurality of grains of the filamentary sol-gel abrasive grain and secondary abrasive grain can be used for the blend of abrasive grains in combination with the agglomerated abrasive grain granules. In another embodiment, the agglomerate of the filamentary sol-gel abrasive grain that includes a plurality of grains of the filamentary sol-gel abrasive grain and secondary abrasive grain can be used for an abrasive for the abrasive tools of the invention without blending with the agglomerated abrasive grain granules. Typical features of the agglomerates of filamentary sol-gel abrasive grains are as discussed above for the agglomerated abrasive grain granules.

[0117] Generally, by selecting different grit sizes for blends of the filamentary grain and the non-filamentary grain, one may adjust the grinding performance of abrasive tools containing the agglomerated grains. For example, a tool used in a grinding operation operated at a relatively high material removal rate (MRR) can be made with a grain agglomerate comprising a 46 grit (355 microns) square or blocky alumina grain and an 80 grit (180 microns) TG2 grain. In a similar fashion, tools tailored for high MRR operations may contain agglomerates of just the 46 grit square or blocky alumina grain blended with loose, non-agglomerated grains of 80 grit TG2 grain. In another example, a tool used in a grinding operation requiring a controlled, fine surface finish, without scratches on the workpiece surface, can be made with a grain agglomerate comprising a 120 grit (106 microns) square or blocky alumina grain and an 80 grit (180 microns) TG2 grain. In an alternative embodiment, tools tailored for fine surface quality grinding or polishing operations may contain agglomerates of just the 120 grit (106 microns) square or blocky alumina grain blended with loose, non-agglomerated grains of 80 grit (180 microns) TG2 grain.

[0118] Any bond (binding) material typically used for bonded abrasive tools in the art can be used for the binding material of the agglomerated abrasive grain granules (hereinafter "the first binding material") and the second binding material of the agglomerate of filamentary sol-gel abrasive grains. Preferably, the first and second binding materials each independently include an inorganic material, such as ceramic materials, vitrified materials, vitrified bond compositions and combinations thereof, more preferably ceramic and vitrified materials of the sort used as bond systems for vitrified bonded abrasive tools. These vitrified bond materials may be a pre-fired glass ground into a powder (a frit), or a mixture of various raw materials such as clay, feldspar, lime, borax and soda, or a combination of fritted and raw materials. Such materials fuse and form a liquid glass phase at temperatures ranging from about 500 to about 1400°C and wet the surface of the abrasive grain to create bond posts upon cooling, thus holding the abrasive grain within a composite structure. Examples of suitable binding materials for use in the agglomerates can be found, for example, in U.S. Pat. No. 6,679,758 B2 and U.S. Patent Application Publication No. 2003/0194954. Preferred binding materials are characterized by a viscosity of about 345 to 55,300 poise at about 1180°C, and by a melting temperature of about 800 to about 1300°C.

[0119] In a preferred example, the first and second binding materials are each independently a vitrified bond composition comprising a fired oxide composition of SiO_2, B_2O_3, Al_2O_3, alkaline earth oxides and alkali oxides. In one case the fired oxide composition includes 71 wt % SiO_2 and B_2O_3, 14 wt % Al_2O_3, less than 0.5 wt % alkaline earth oxides and 13 wt % alkali oxides.

[0120] The first and second binding materials also can be a ceramic material, including silica, alkali, alkaline-earth, mixed alkali and alkaline-earth silicates, aluminum silicates, zirconium silicates, hydrated silicates, aluminates, oxides, nitrides, oxynitrides, carbides, oxycarbides and combinations and derivatives thereof. In general, ceramic materials differ from glassy or vitrified materials in that the ceramic materials comprise crystalline structures. Some glassy phases may be present in combination with the crystalline structures, particularly in ceramic materials in an unrefined state. Ceramic materials in a raw state, such as clays, cements and minerals, can be used herein. Examples of specific ceramic materials suitable for use herein include silica, sodium silicates, mullite and other alumino silicates, zirconia-mullite, magnesium aluminate, magnesium silicate, zirconium silicates, feldspar and other alkali-alumino-silicates, spinels, calcium aluminate, magnesium aluminate and other alkali aluminates, zirconia, zirconia stabilized with yttria, magnesia, calcia, cerium oxide, titania, or other rare earth additives, talc, iron oxide, aluminum oxide, bohemite, boron oxide, cerium oxide, alumina-oxynitride, boron nitride, silicon nitride, graphite and combinations of these ceramic materials.

[0121] In general, the first and second binding materials are each independently used in powdered form and optionally, are added to a liquid vehicle to insure a uniform, homogeneous mixture of binding material with abrasive grain during manufacture of the agglomerates.

[0122] A dispersion of organic binders is preferably added to the powdered binding material components as molding or processing aids. These binders may include dextrins, starch, animal protein glue, and other types of glue; a liquid component, such as water, solvent, viscosity or pH modifiers; and mixing aids. Use of organic binders improves agglomerate uniformity, particularly the uniformity of the binding material dispersion on the grain, and the structural quality of the prefired or green agglomerates, as well as that of the fired abrasive tool containing the agglomerates. Because the organic binders are burnt off during firing of the agglomerates, they do not become part of the finished agglomerate nor of the finished abrasive tool. An inorganic adhesion promoter may be added to the mixture to improve adhesion of the binding materials to the abrasive grain as needed to improve the mix quality. The inorganic adhesion promoter may be used with or without an organic binder in preparing the agglomerates.

[0123] Although high temperature fusing binding materials are preferred in the agglomerates of the invention, the binding material also may comprise other inorganic binders, organic binders, organic bond materials, metal bond materials and combinations thereof. Binding materials used in the abrasive tool industry as bonds for organic bonded abrasives, coated abrasives, metal bonded abrasives and the like are preferred.

[0124] The binding material is present at about 0.5 to about 15 volume %, more preferably about 1 to about 10 volume %, and most preferably about 2 to about 8 volume % of the agglomerate. The preferred volume % porosity within the agglomerate is as high as technically possible within the agglomerate mechanical strength limitations needed to manufacture an abrasive tool and to grind with it. Porosity may range from about 30 to about 88 volume %, preferably about 40 to about 80 volume % and most preferably, about 50 to about 75 volume %. A portion (e.g., up to about 75 volume %) of the porosity within the agglomerates is preferably present as interconnected porosity, or porosity permeable to the flow of fluids, including liquids (e.g., grinding coolant and swarf) and air.

[0125] The density of the agglomerates can be expressed in a number of ways. The bulk density of the agglomerates can be expressed as the LPD. The relative density of the agglomerates can be expressed as a percentage of initial relative density, or as a ratio of the relative density of the agglomerates to the components used to make the agglomerates, taking into account the volume of interconnected porosity in the agglomerates.

[0126] The initial average relative density, expressed as a percentage, can be calculated by dividing the LPD by a theoretical density of the agglomerates assuming zero porosity. The theoretical density can be calculated according to the volumetric rule of mixtures method from the weight percentage and specific gravity of the binding material and of the abrasive grain contained in the agglomerates. For the agglomerates useful in the invention, a maximum percent relative density is about 50 volume %, with a maximum percent relative density of about 30 volume % being more preferred.

[0127] The relative density can be measured by a fluid displacement volume technique so as to include interconnected porosity and exclude closed cell porosity. The relative density is the ratio of the volume of the agglomerates measured by fluid displacement to the volume of the materials used to make the agglomerates. The volume of the materials used to make the agglomerates is a measure of the apparent volume based on the quantities and packing densities of the abrasive grain and binder material used to make the agglomerates. In a preferred embodiment, a maximum relative density of the agglomerates preferably is about 0.7, with a maximum relative density of about 0.5 being more preferred.

[0128] The agglomerates of abrasive grains can be formed by a variety of techniques into numerous sizes and shapes. These techniques can be carried out before, during or after firing the initial ("green") stage mixture of grain and binding material. The step of heating the mixture to cause the binding material to melt and flow, thus adhering the binding material to the grain and fixing the grain in an agglomerated form, is referred to as firing, calcining or sintering. Any method known in the art for agglomerating mixtures of particles can be used to prepare the abrasive agglomerates. For example, methods that can be used are disclosed in U.S. Pat. No. 6,679,758 B2, U.S. Patent Application Publication No. 2003/0194954, and U.S. Patent Application Publication No. 2007/0074456, the entire teachings of which are incorporated herein by reference, can be used.

[0129] The grinding wheel can include generally any type of conventional abrasive product. Examples of such conventional abrasive products include grinding wheels, cutoff wheels and honing stones, which are comprised of a bond component and a blend of abrasive grains, or an agglomerate of filamentary sol-gel abrasive grains, as described above. Suitable methods for making bonded abrasive tools are disclosed in U.S. Pat. Nos. 5,129,919, 5,738,696 and 5,738,697, the entire teachings of which are incorporated herein by reference.

[0130] Any bond normally used in abrasive articles can be employed in the present invention. The amounts of bond and abrasive vary typically from about 3% to about 25% bond and about 10% to about 70% abrasive grain, by volume, of the tool. Preferably, the blend of abrasive grains are present in the bonded abrasive tool in an amount of about 10-60%, more preferably about 20-52%, by volume of the tool. Also, when the agglomerate of filamentary sol-gel abrasive grains is used without blending with the agglomerated abrasive granules, the amount of the agglomerate of filamentary sol-gel abrasive grains are present in the bonded abrasive tool in an amount of about 10-60%, more preferably about 20-52%, by volume of the tool. A preferred amount of bond can vary depending upon the type of bond used for the abrasive tool.

[0131] In one implementation, the abrasive tool used as grinding wheel 14 can be bonded with a resin bond. Suitable resin bonds include phenolic resins, urea-formaldehyde resins, melamine-formaldehyde resins, urethane resins, acrylate resins, polyester resins, aminoplast resins, epoxy resins, and combinations thereof. Examples of suitable resin bonds and techniques for manufacturing such bonds can be found, for example, in U.S. Pat. Nos. 6,251,149; 6,015,338; 5,976,204; 5,827,337; and 3,323,885, the entire teachings of which are incorporated herein by reference. Typically, the resin bonds are contained in the compositions of the abrasive tools in an amount of about 3%-48% by volume. Optionally, additives, such as fibers, grinding aids, lubricants, wetting agents, surfactants, pigments, dyes, antistatic agents (e.g., carbon black, vanadium oxide, graphite, etc.), coupling agents (e.g., silanes, titanates, zircoaluminates, etc.), plasticizers, suspending agents and the like, can be further added into the resin bonds. A typical amount of the additives is about 0-70% by volume of the tool.

[0132] In another implementation, the bond component of the tool comprises an inorganic material selected from the group consisting of ceramic materials, vitrified materials, vitrified bond compositions and combinations thereof. Examples of suitable bonds may be found in U.S. Pat. Nos. 4,543,107; 4,898,597; 5,203,886; 5,025,723; 5,401,284; 5,095,665; 5,711,774; 5,863,308; and 5,094,672, the entire teachings of all of which are incorporated herein by reference. For example, suitable vitreous bonds for the invention include conventional vitreous bonds used for fused alumina or sol-gel alumina abrasive grains. Such bonds are described in U.S. Pat. Nos. 5,203,886, 5,401,284 and 5,536,283. These vitreous bonds can be fired at relatively low temperatures, e.g., about 850-1200° C. Other vitreous bonds suitable for use in the invention may be fired at temperatures below about 875° C. Examples of these bonds are disclosed in U.S. Pat. No. 5,863,308. Preferably, the vitreous bonds employed can be fired at a temperature in a range of between about 850° C and about 1200° C. In one specific example, the vitreous bond is an alkali boro alumina silicate (see, for example, U.S. Pat. Nos. 5,203,886, 5,025,723 and 5,711,774).

[0133] The vitreous bonds are present in the compositions of the abrasive tools typically in an amount of less than about 28% by volume, such as between about 3 and about 25 volume %; between about 4 and about 20 volume %; and between about 5 and about 18.5 volume %.

[0134] Optionally, the bond component of the abrasive tool and the binding materials, including the first and second binding materials, can include the same type of bond compositions, such as a vitrified bond composition comprising a fired oxide compositions of SiO_2, B_2O_3, Al_2O_3, alkaline earth oxides and alkali oxides.

[0135] The filamentary sol-gel abrasive grain in combination of the agglomerated abrasive grain, or the agglomerate of filamentary sol-gel abrasive grain with or without blending with the agglomerated abrasive grain granules, allows the production of bonded abrasive tools with a highly porous and permeable structure. However, optionally, conventional pore inducing media such as hollow glass beads, solid glass beads, hollow resin beads, solid resin beads, foamed glass particles, bubbled alumina, and the like, may be incorporated in the present wheels thereby providing even more latitude with respect to grade and structure number variations.

[0136] The bonded abrasive tools that can be used as grinding wheel 14 preferably contain from about 0.1% to about 80% porosity by volume. More preferably, they contain from about 35% to about 80%, and even more preferably they contain from about 40% to about 68 volume %, of the tool.

[0137] When a resin bond is employed, the combined blend of abrasive grains and resin bond component is cured at a temperature, for example, in a range of between about 60°C and about 300°C to make a resinoid abrasive tool. When a vitreous bond is employed, the combined blend of abrasive grains and vitreous bond component is fired at a temperature, for example, in a range of between about 600°C and about 1350°C to make a vitrified abrasive tool.

[0138] When a vitreous bond is employed, the vitrified abrasive tools typically are fired by methods known to those skilled in the art. The firing conditions are primarily determined by the actual bond and abrasives used. Firing can be performed in an inert atmosphere or in air. In some embodiments, the combined components are fired in an ambient air atmosphere. As used herein, the phrase "ambient air atmosphere," refers to air drawn from the environment without treatment.

[0139] Molding and pressing processes to form the wheel can be performed by methods known in the art. For example, U.S. Patent No. 6,609,963, titled *Vitrified Superabrasive Tool and Method of Manufacture,* issued to Li et al. on August 26, 2003, the entire teachings of which are incorporated herein by reference, teaches one such suitable method.

[0140] Examples of commercially available wheels that can be employed as grinding wheel 14 include wheels available under the designation of ALTOS® or ALTOS IPX® from Saint-Gobain Abrasives, Inc, Worcester, Mass. These abrasive tools are highly porous and permeable grinding tools that have high metal removal rates, improved form holding and long wheel life, along with a greatly reduced risk of metallurgical damage. These permeable abrasive tools can employ, for example, sintered sol gel alumina ceramic grains (Saint-Gobain Abrasives in Worcester, Mass.) with an average aspect ratio of about 7.5:1, such as Norton® TG2 or TGX Abrasives (hereinafter "TG2"), as a filamentary abrasive grain. TG1 grains also can be used. Examples of wheel specifications that can be employed include, for instance, ALTOS TGX 120F13VCF5; ALTOS TGX 120G13VCF5; ALTOS TGX 120H13VCF5; ALTOS TGX 80E13VCF5; ALTOS TGX 80G13VCF5; ALTOS TGX 80I12VCF5; ALTOS IPX120H13VCF5; ALTOS IPX120I13VCF5; ALTOS IPX120J12VCF5.

[0141] Surprisingly, it was found that by using wheels such as described above, e.g., wheels disclosed in U.S. Patent No. 5,738,696, U.S. Patent No. 5,738,697 and in U.S. patent Application Publication No. 20070074456 A1, such as ALTOS@ or ALTOS IPX®, the surface quality of the roll can be controlled through changing wheel speed and/or dressing parameters. In contrast, when using conventional technology, the surface quality of the roll can only be achieved by changing the grit size of the wheel.

[0142] In specific implementations the grinding wheel described above is used in rough roll grinding operations. Such operations generally involve fast material removal rates, e.g., of 2 to 10 $mm^3/s/mm$, using grit sizes coarser than or below 60 grit. The roll grinding operation can be continued to achieve a desired surface quality, e.g., a semi-finished or finished surface.

[0143] Roll grinding processes often include operations that relate to removing bond material and worn abrasive grains to expose fresh abrasives. Such operations generally are known as "dressing" and are important in controlling the finish and/or dimensional accuracy of the workpiece, reducing thermal damage, and so forth.

[0144] Shown in FIG. 2, for example, is arrangement 20 which includes roller 12, grinding wheel 14 and dressing stick 26. Shown in FIG. 3, is arrangement 30, including roller 12, grinding wheel 14 and rotating diamond dressing system 38, e.g., a dressing wheel or roll. Other suitable types of dressing tools can be utilized. Grinding wheel 14 can be a grinding wheel such as described above or another type wheel suitable for the roll grinding process.

[0145] In roll grinding operations conducted, for instance, with wheels that contain cubic boron nitride (cBN) abrasive grains in an organic or a vitrified bond, dressing is performed when mounting a new wheel for the run out and opening the wheel surface prior to the first run and roll grinding machines typically are provided with a stationary rotary dresser. In addition, wheels that include cBN grains often are re-dressed after several passes of the wheel, using a stationary dressing tool that is outside the grinding zone. The dressing operation generally interrupts the roll grinding process since in order to be dressed, the wheel needs to exist the grinding zone. This type of dressing may be thought of as "sequential" dressing.

[0146] Shown in FIGS. 4A and 4B, for example, is arrangement 40 that includes roller 12 having ends 16 and 18 which is ground by grinding wheel 14, which is, for instance, a permeable grinding wheel such as described above. Typically, grinding wheel 14 traverses the roll from one end, as shown, e.g., in FIG. 4A, to the other end, as shown, e.g., in FIG. 4B, for several passes after which it exits the grinding zone, e.g., moves away from roller 12, and is dressed by rotary roll dresser 42. In preferred implementations, the rotary dressing roll 42 is profiled to avoid feed lines by breaking the edges of the grinding wheel. As shown in FIGS. 4A and 4B, rotary roll dresser 42 is stationed at or near end 16 of roller 12 and does not travel along the length of the roll (direction of arrow C).

[0147] One aspect of the invention relates to a process and apparatus for grinding mill rolls in which a dressing tool is maintained in contact with the grinding wheel as the grinding wheel traverses the surface of the roll. In preferred arrangements, the dressing tool travels together with the grinding wheel, along the length of the mill roll (direction of arrow C). According to this aspect of the invention, the dressing operation is conducted without exiting the grinding wheel out of the grinding zone and this type of dressing is referred to herein as "continuous" dressing.

[0148] Shown in FIGS 5A and 5B, for example, is arrangement 50, comprising roll 12 and assembly 52, which includes grinding wheel 54 and a dressing tool such as, for instance, a rotary dressing tool, e.g. rotary dressing roll 56. In preferred implementations, the rotary dressing roll is profiled to avoid feed lines by breaking the edges of the grinding wheel. In specific embodiments, grinding wheel 54 is a permeable wheel such as described above, e.g., an ALTOS@ or ALTOS IPX® grinding wheel. Grinding wheels, such as, for instance, wheels disclosed in U.S. Patent No. 6,988,937 B2, titled *Method of Roll Grinding,* issued to Bonner et al. on January 24, 2006, the teachings of which are incorporated herein by reference in their entirety, also can be employed. Other types of wheels suitable for roll grinding can be used in arrangement 50. Examples include but are not limited to commercially available grinding wheels from Saint-Gobain Abrasives, Inc. Worcester, Mass. under the designations of VORTEX®, Neptune®, or Quantum®, as well as grinding wheels available from Tyrolit, Carborandum, Theleico, Atlantic, and other manufacturers. In some implementations the wheel has a vitrified bond.

[0149] As shown in FIGS. 5A and 5B, rotary dressing roll 56 accompanies grinding wheel 54 as the wheel traverses roll 12 between ends 16 and 18 (direction indicated by arrow C). The movement of assembly 52 along the length of the roll (direction of arrow C) can be carried out by operationally linking grinding wheel 54 to rotary dressing roll 18. Other means for dressing the grinding wheel as it traverses roll 12 between ends 16 and 18 also can be employed. For instance, the motion of the grinding wheel and that of the dressing tool can be subject to controls set to provide contact between the two, as the grinding wheel traverses roll 12. Independent systems can be employed for: (i) traversing a rotating grinding wheel across the surface of a mill roll maintaining contact of the grinding wheel with the mill roll; and (ii) maintaining contact between the rotating grinding wheel traversing across the surface of the mill roll and a dressing tool, e.g., a rotating dressing tool. The systems or assembly 52 can include translational stages, gears, controls and other devices, as known in the art. In preferred implementations, the dressing operation illustrated in FIGS. 5A and 5B can be integrated in the roll grinding machine, enabling CNC control.

[0150] In the roll grinding process illustrated by FIGS. 5A and 5B, the grinding wheel can be rotated continuously during the movement of the grinding wheel from one end of a mill roll to the other end. If desired, the dressing tool can be rotated intermittently, for instance, every few inches as the grinding wheel progresses between ends 16 and 18.

[0151] Dressing protocols can be established depending on the type of grinding wheel, mill roll material, process parameters, and so forth. The speed ratio of the rotary dresser, e.g., rotary dressing roll 56, versus the wheel speed can be adjusted precisely, allowing the wheel to be conditioned in very aggressive cutting action for rough grinding passes (or for first stands in mill) and also to get a smooth surface finish due to a lower roughness of wheel surface generated by the dressing operation. Since rough edges of the wheel can be smoothed continuously or quasi-continuously (with intermittent rotation of the dressing tool), spiral and other defects in the roll surface are reduced or eliminated.

[0152] The grinding process, preferably including the continuous dressing operation described above, and/or the permeable grinding wheel described above, e.g., an ALTOS@ or ALTOS IPX® type grinding wheel, is conducted to obtain a desired surface finish. For instance, grinding can be continued to obtain a surface that preferably is free of undulations, lines, marks and other surface irregularities, since if such irregularities remain, they will be transferred from the roll surface onto the surface of metal being rolled by the defective roll. In many implementations of the invention, the surface finish is controlled by the speed ratio of the grinding wheel, e.g., an ALTOS@ or ALTOS IPX® type grinding wheel, versus the roll speed.

[0153] One way for describing the quality of the surface makes use of "Ra" which is an industry standard unit (that can be expressed in micrometers or microinches) for surface finish quality representing the average roughness height, i.e., the average absolute distance from the mean line of the roughness profile within the evaluation length. In some examples, the surface of the roll is finished to a surface roughness measurement of Ra=0.2 to Ra=10μm.

[0154] In other examples, the grinding operation results in a surface quality characterized by 160 to 180 peaks (or scratches) per inch. The peak count ("Pc", i.e., an industry standard representing the number of peaks per inch which project through a selected band centered about the mean line) is an important parameter of the surface of metal sheets that will be painted during the fabrication of automotive body parts. A surface with too few peaks is as undesirable as a surface with too many peaks or a surface with excessive roughness.

[0155] Several examples that are not intended to be limiting are provided below.

EXEMPLIFICATION

[0156] In one example, 1,400 rolls were processed using a single ALTOS® type wheel and a continuous dressing arrangement such as illustrated in FIGS. 5A and 5B. About 0.12 mm were removed from the roll radius at a material removal rate (MRR') of 12 mm^3/s/mm. The G-ratio was about 35 and the total process time was about 15 minutes. The wheel worked on all profiles and was able to achieve a desired Ra by changing the wheel speed.

[0157] In another example, a single VORTEX® type wheel, dressed as illustrated in FIGS 5A and 5B, processed 60 rolls, removing about 0.2 mm from the roll radius at a MRR' of 5 mm^3/s/mm. The G-ratio was about 2. The wheel worked on all profiles and was able to achieve a desired Ra by changing the wheel speed.

[0158] In a further example, a single Quantum wheel (organic specification) dressed as illustrated in FIGS 5A and 5B, processed 250 rolls removing about 0.25 mm on the roll radius. The MRR' was 8 mm^3/s/mm and the G-ratio was about 8. The wheel worked on all profiles and was able to achieve a desired Ra by changing the wheel speed.

[0159] In contrast, a single standard organic wheel, without continuous dressing, processed 190 rolls, removing about 0.25 mm on roll radius. The time needed to process rolls using the organic standard wheel, without continuous dressing, was about 30-40 minutes per roll. The MRR' was 7 mm^3/s/mm and the G-ratio was 6. The grit had to be changed to achieve a desired Ra.

[0160] While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

[0161] The Abstract of the Disclosure is provided solely to comply with U.S. requirements and, as such, is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description, with each claim standing on its own as defining separately claimed subject matter.

Claims

1. A process for grinding mill rolls, the process comprising:

   a. mounting a grinding wheel on a roll grinding machine;
   b. bringing the grinding wheel into contact with a rotating mill roll;
   c. traversing the grinding wheel across a surface of the mill roll while maintaining continuous contact of the grinding wheel with the surface of the mill roll;
   d. dressing the grinding wheel while the grinding wheel is in contact with the mill roll; and
   e. grinding the surface of the mill roll.

2. The process of Claim 1, wherein the grinding wheel is dressed with a rotary dressing tool.

3. The process of Claim 1 or Claim 2, wherein the dressing tool is rotated continuously.

4. The process of Claim 1 or Claim 2, wherein the dressing tool is rotated intermittently.

5. The process of any one of the preceding Claims, wherein the process is under computer numerical control.

6. The process of any one of the preceding Claims, wherein the surface of the mill roll that is ground in step e is a cylindrical surface.

7. The process of any one of the preceding Claims, wherein the grinding wheel includes a vitrified bond.

8. The process of any one of the preceding Claims, wherein the grinding wheel comprises about 55% to about 80%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for roll grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof.

9. The process of any one of Claims 1-7, wherein the grinding wheel has an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprises: (i) prior to curing the grinding wheel, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the grinding wheel, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof.

10. The process of any one of Claims 1-7, wherein the grinding wheel comprises about 40% to about 54%, by volume, interconnected porosity defined by a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1, and abrasive grain and bond in amounts effective for grinding, and having an air permeability measured in cc air/second/inch of water of at least 0.22 times the cross-sectional width of the abrasive grain, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the fibrous particles consist of materials selected from the group consisting of abrasive grain, filler, combinations thereof, and agglomerates thereof.

11. The process of any one of Claims 1-7, wherein the grinding wheel has an air permeability measured in cc air/second/inch of water of at least 0.44 times the cross-sectional width of the abrasive grain, and comprises: (i) prior to curing

the abrasive article, a matrix of fibrous particles, the fibrous particles having a length to diameter aspect ratio of at least 5:1; (ii) after curing the abrasive article, about 55% to about 80%, by volume, interconnected porosity, the interconnected porosity being defined by the matrix of fibrous particles; and (iii) abrasive grain and bond in amounts effective for grinding, wherein the interconnected porosity provides an open structure of channels permitting passage of fluid or debris through the abrasive article during grinding, and wherein the matrix of fibrous particles is at least one layer of structured filler selected from the group consisting of glass mat, organic mat, ceramic fiber mat, and combinations thereof.

12. The process of any one of Claims 1-7, wherein the wheel comprises:

a blend of abrasive grains including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0, or an agglomerate thereof; and ii) agglomerated abrasive grain granules including a plurality of abrasive grains held in a three-dimensional shape by a binding material;
a bond; and
at least about 35 volume percent porosity.

13. The process of any one of Claims 1-7, wherein the wheel comprises:

an agglomerate including: i) a filamentary sol-gel alumina abrasive grain having a length-to-cross-sectional-width aspect ratio of greater than about 1.0; ii) a non-filamentary abrasive grain; and iii) a binding material, wherein the non-filamentary abrasive grain and filamentary sol-gel alumina abrasive grain are held in a three-dimensional shape by the binding material;
a bond; and
at least about 35 volume percent porosity.

14. A method for dressing a wheel grinding a mill roll, the method comprising:

maintaining contact between the wheel and a rotary dressing tool as the wheel traverses a surface of the mill roll.

15. An apparatus for grinding mill rolls includes a dressing tool that is operationally linked to a grinding wheel to maintain contact between the dressing tool and the grinding wheel as the grinding wheel traverses a surface of the mill roll.

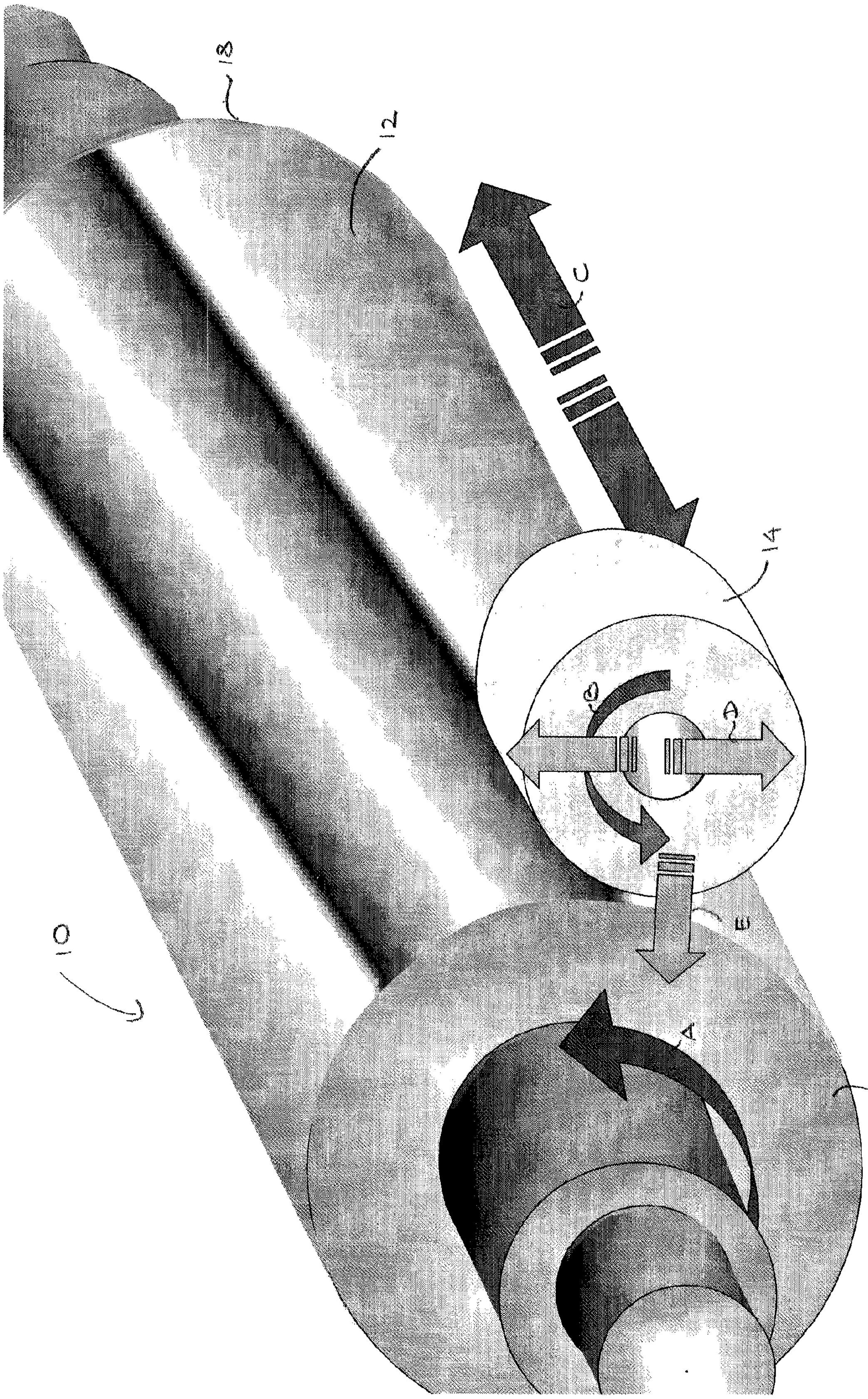

FIG. 1

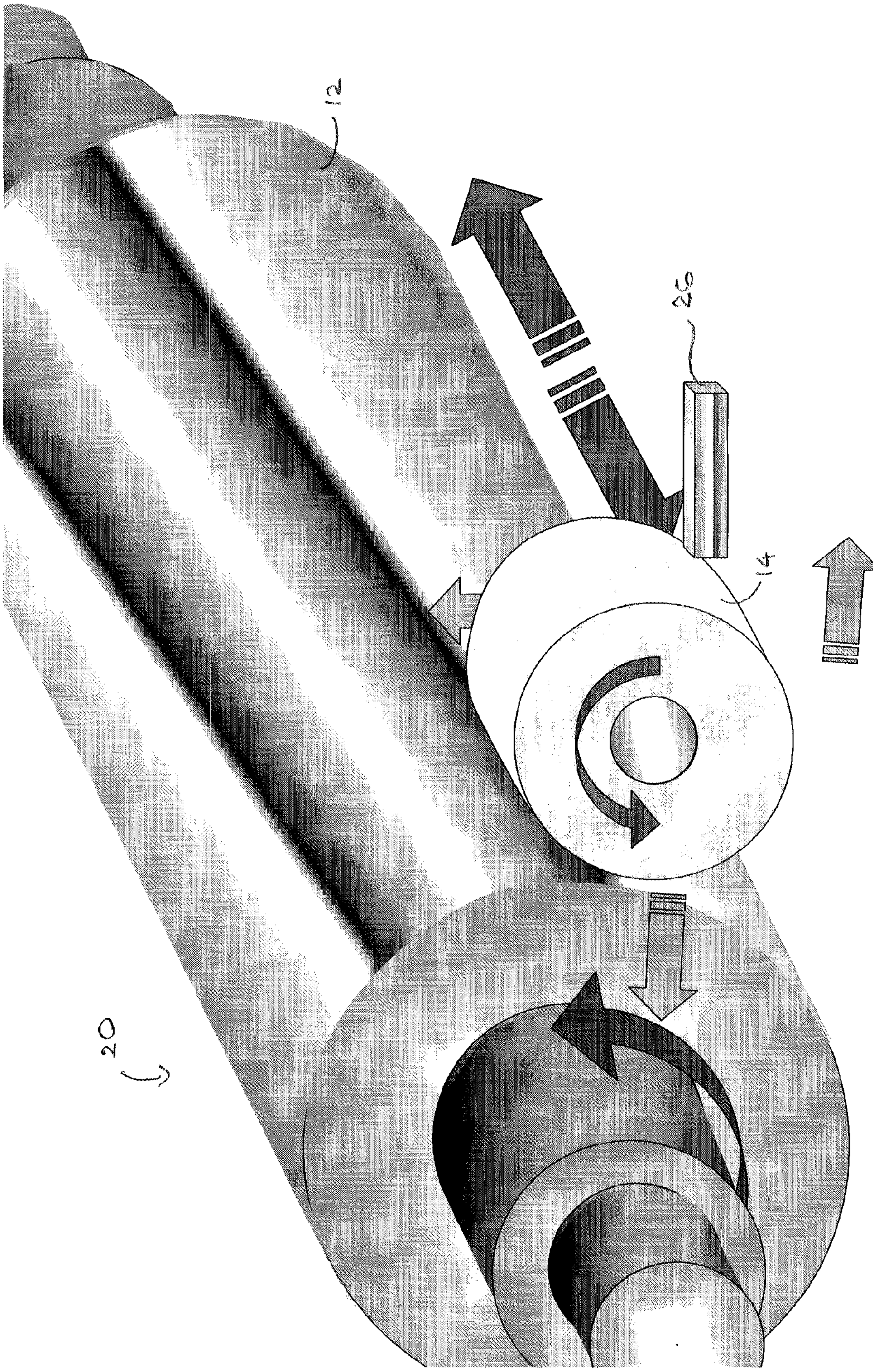

FIG. 2

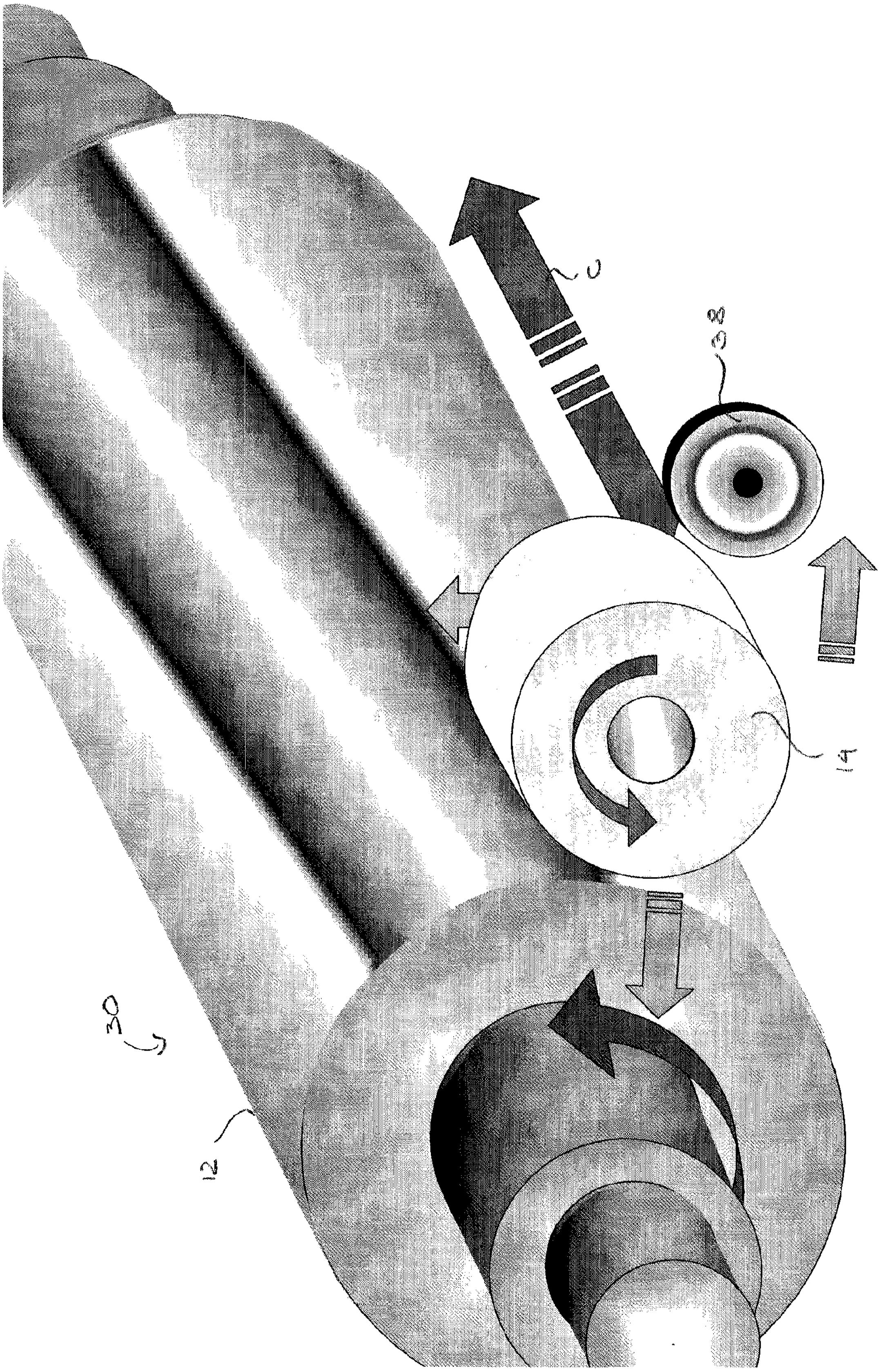

FIG. 3

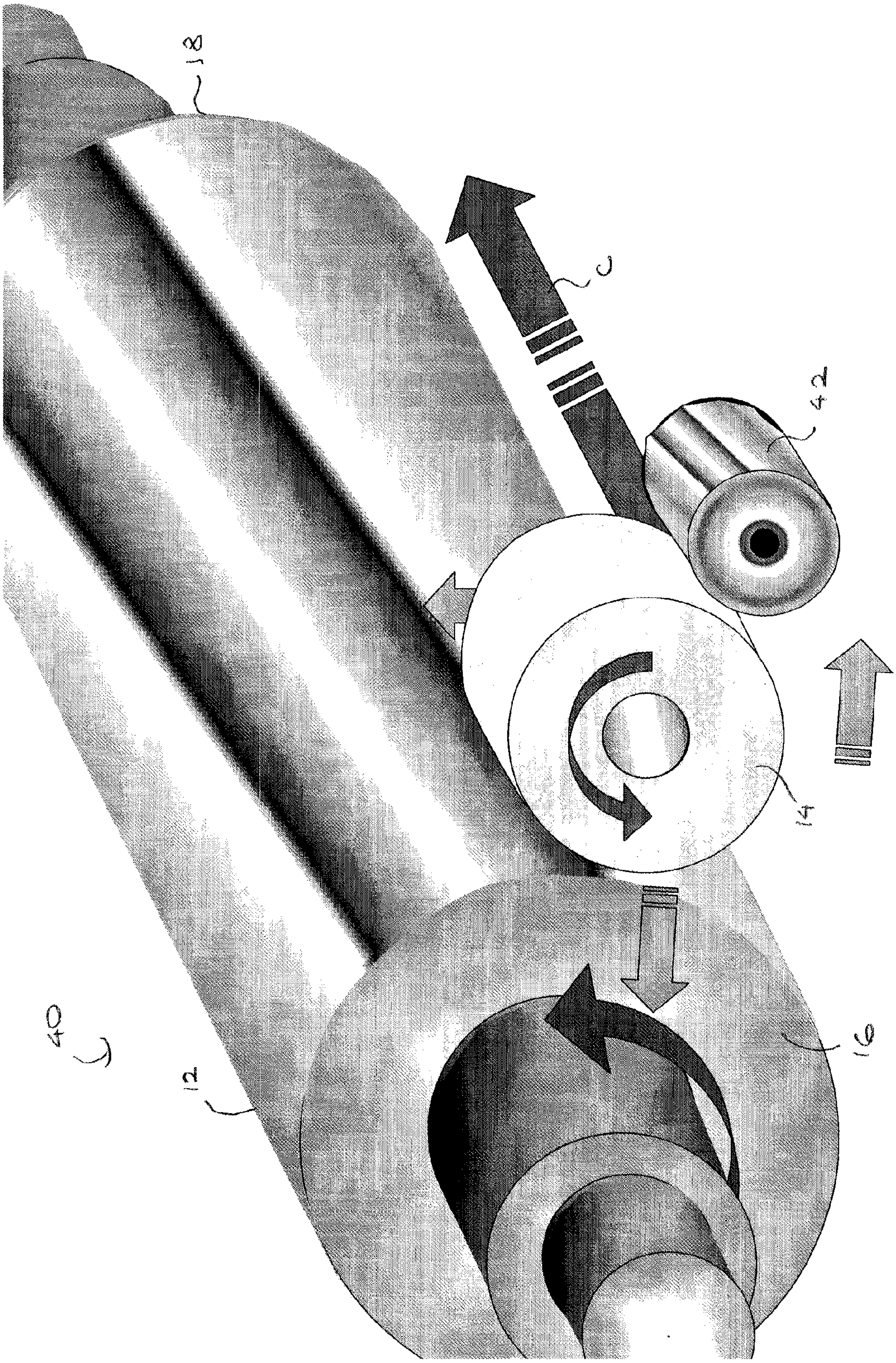

FIG. 4A

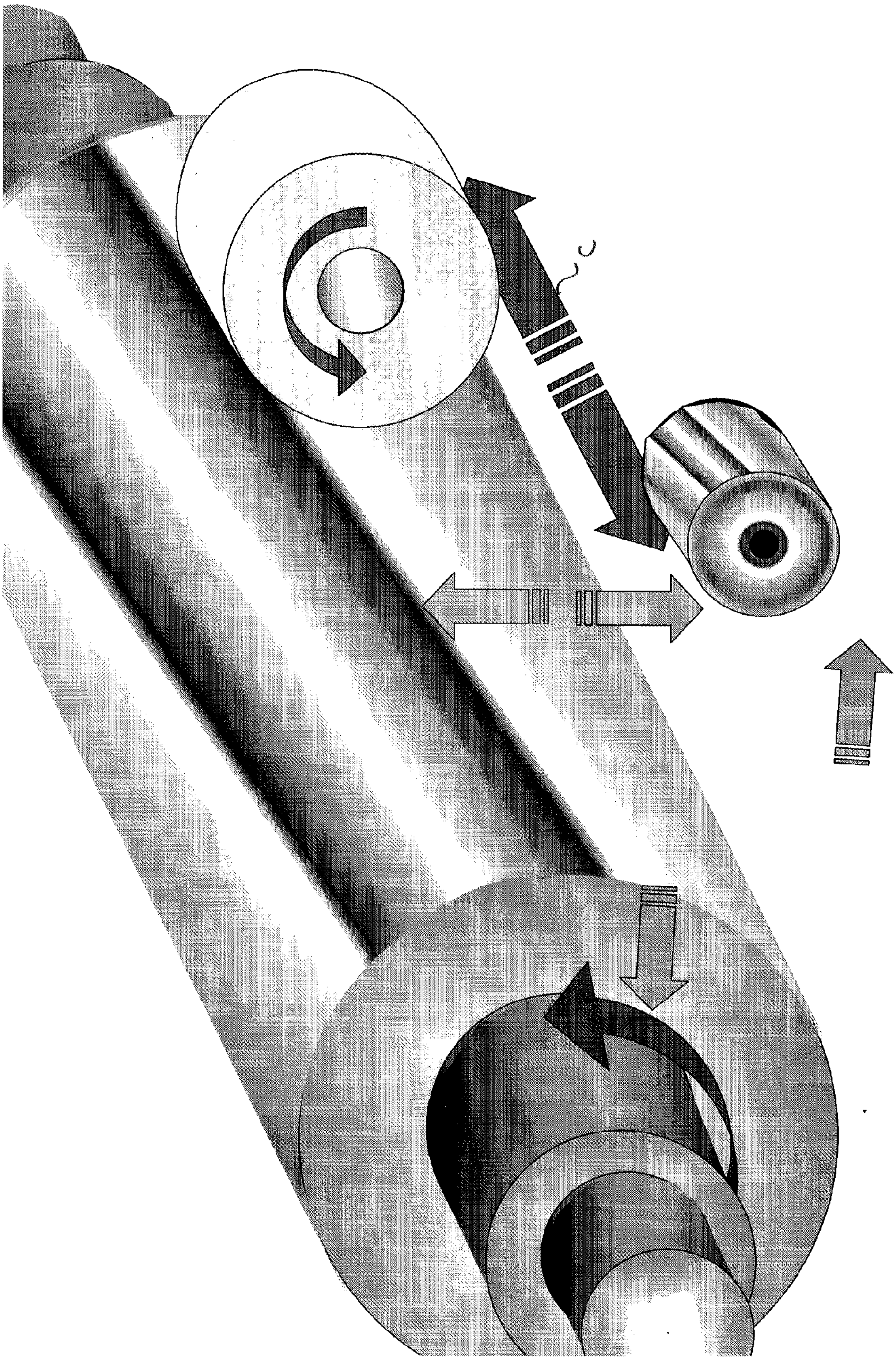

Fig. 40

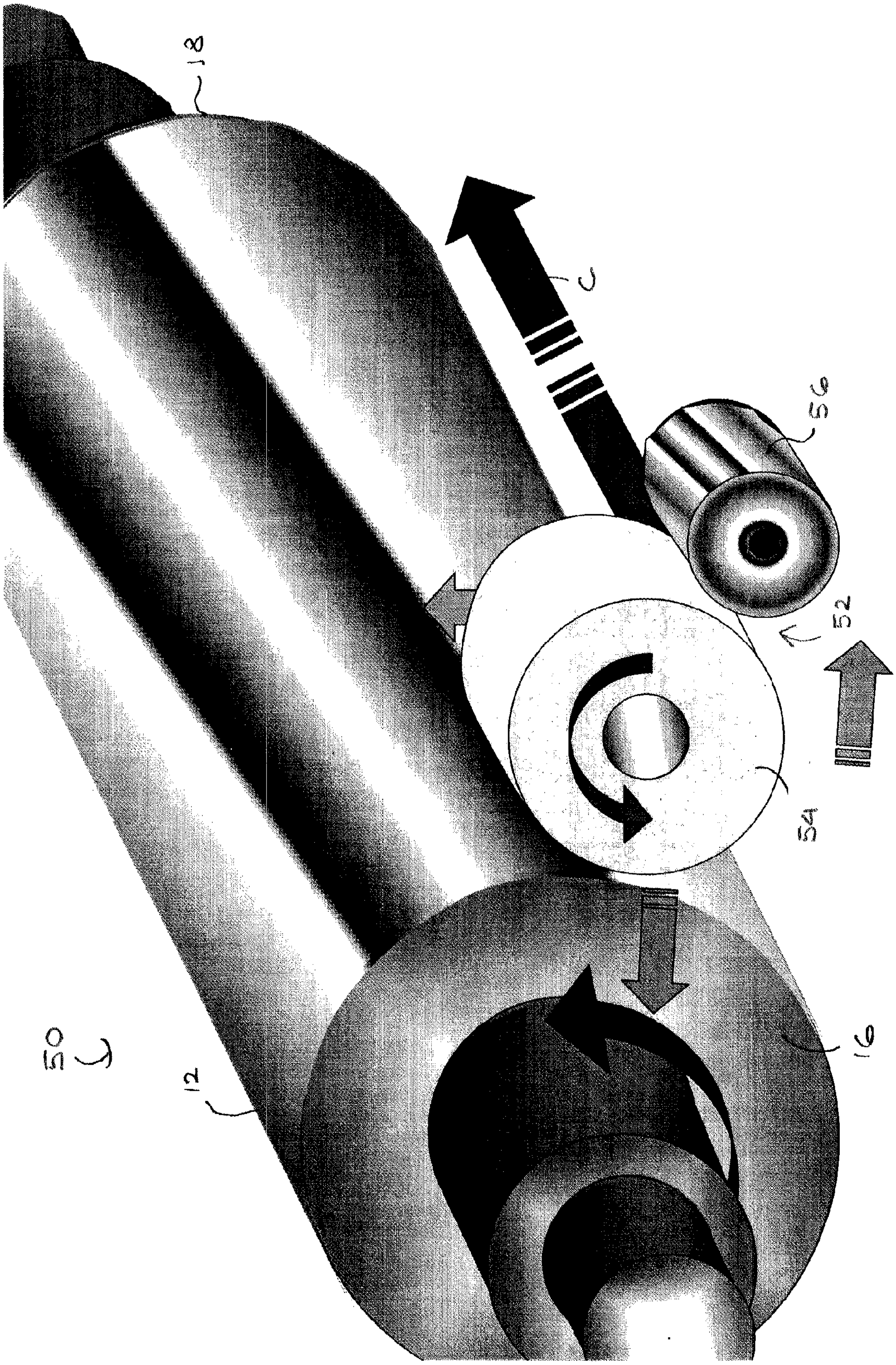

FIG. 5A

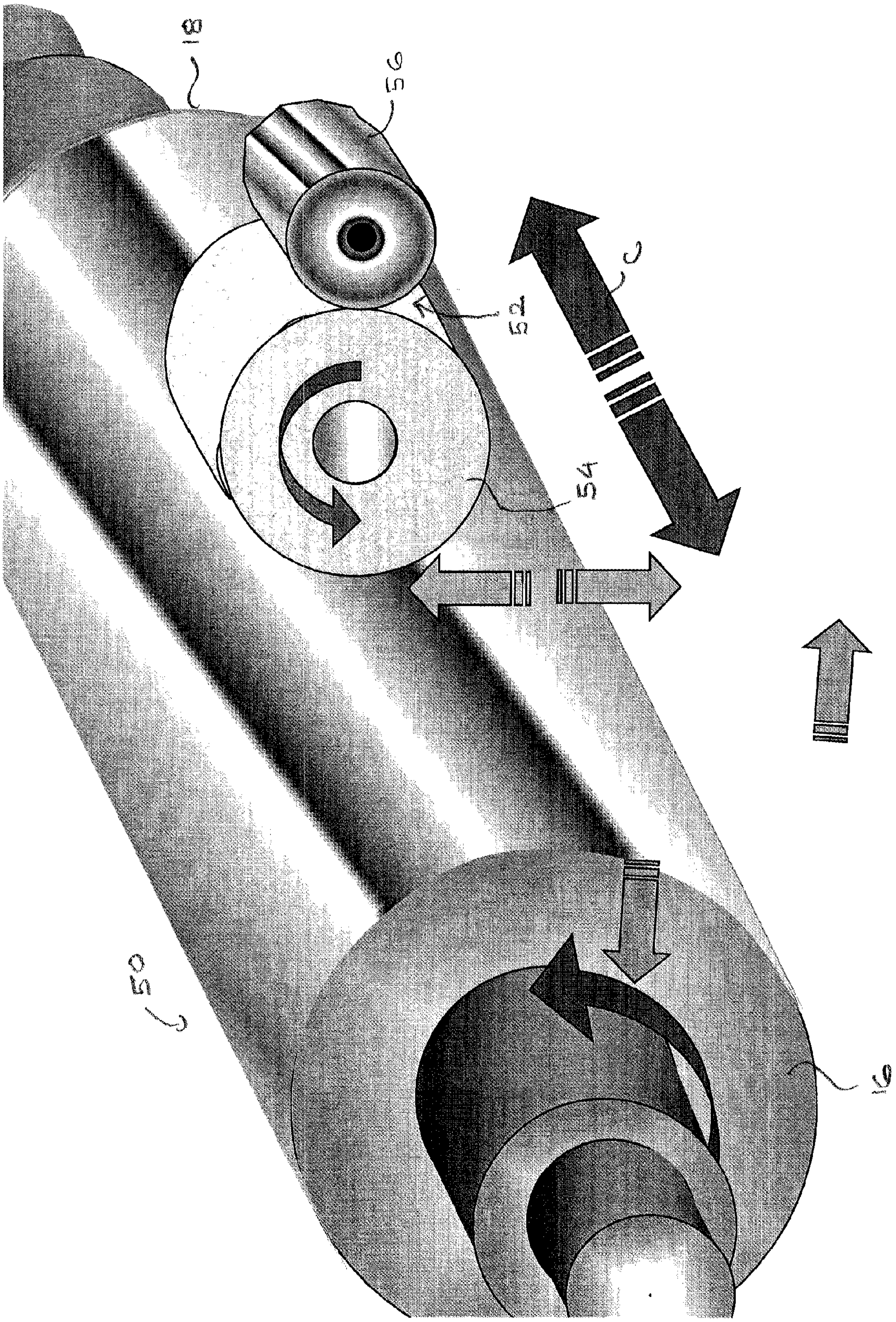

Fig. 5B

REFERENCES CITED IN THE DESCRIPTION

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