(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
08 June 2023 (08.06.2023)

WIPO | PCT

(10) International Publication Number
WO 2023/100104 A1

(51) International Patent Classification:
B24D 13/10 (2006.01) *B24B 27/00* (2006.01) *B24D 13/14* (2006.01)

(21) International Application Number: PCT/IB2022/061601

(22) International Filing Date: 30 November 2022 (30.11.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/284,168 30 November 2021 (30.11.2021) US

(71) Applicant: 3M INNOVATIVE PROPERTIES COMPANY [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(72) Inventors: MORIS, Alice B.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). HOLMES, Dean S.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). BEVERIDGE, Jacob S.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(74) Agent: TU, Tingting et al.; 3M Center, Office of Intellectual Property Counsel, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,

(54) Title: ABRASIVE ARTICLES AND SYSTEMS

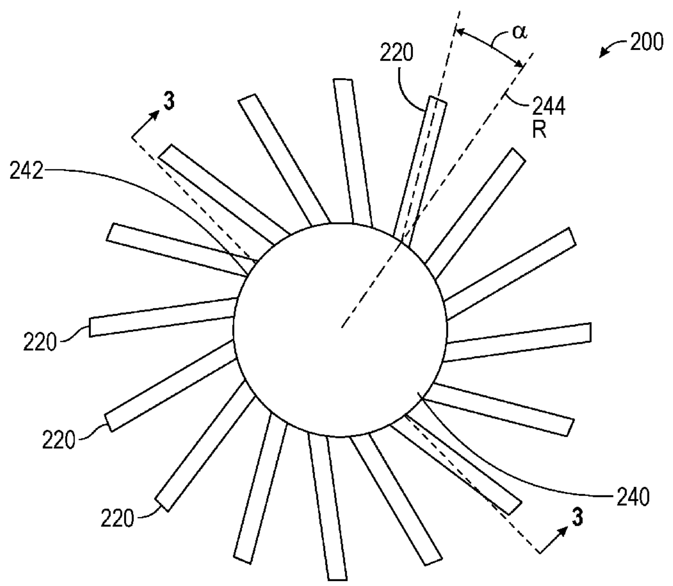


FIG. 2

(57) Abstract: Abrasive articles include a circular center member having an outer edge, a radial line, and a radial plane, a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member, the bristles comprise a plurality of abrasive particles, at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line. The abrasive article can have a first direction of use and a second direction of use opposite to the first direction of use, and the abrading performance achieved by the first and the second directions of use is different from each other. Robotic abrading systems can include such abrasive articles for advantageous operations. Methods of making and using such abrasive articles are also disclosed.

WO 2023/100104 A1

[Continued on next page]

RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

ABRASIVE ARTICLES AND SYSTEMS

BACKGROUND

Abrading, polishing and surface conditioning tools and associated abrasive articles are used in numerous industries, for example, in the woodworking industries, marine industries, automotive industries, construction industries, and so on. Abrasive articles having bristles, such as bristle discs and brushes, are generally known for use in various cleaning, finishing, and deburring applications. There is a need for improved abrasive articles having bristles. Furthermore, traditional abrasive tools and associated abrasive articles present various challenges. In one example, over time workers frequently develop an intuitive sense of when a workpiece is of desired quality or when an abrasive article is wearing out. A robot system using an abrasive article may not acquire such an intuitive sense. In addition, the use of robots to perform abrading tasks can be highly beneficial in some situations, such as when toxic materials are involved, space is constrained, physical access to an area of a workpiece is constrained, work occurs in a hazardous area, and so on. There is a need for improved abrasive articles used for robotic and automate abrasive applications.

SUMMARY

There is a continuing need for abrasive articles that provide enhanced cut and/or easier use, especially for aggressive abrading applications, such as high-pressure deburring operations. The present disclosure provides such abrasive articles.

In one aspect, the present disclosure provides an abrasive article including a circular center member having an outer edge, a radial line, and a radial plane; a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member; wherein the bristles comprise a plurality of abrasive particles; wherein at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line; wherein the slant angle is larger than 0 degree.

Advantageously, an abrasive article having bristles according to the present disclosure provides great abrasive performance such as cut, surface finish and useful abrading life, even for aggressive abrading applications. Additionally, an abrasive article having bristles according to the present disclosure, unexpectedly, shows responsive characteristics adaptable to the force applied on the abrasive article against a workpiece. These advantages make the force control of abrading operation easier, more accurate and more efficient. Furthermore, an abrasive article having bristles according to the present disclosure may require reduced power to perform an abrading operation.

In another aspect, the present disclosure provides an abrasive article including a center member having an outer edge; a plurality of extruded bristles extending outward from the outer edge of the center member; wherein the abrasive article has a first direction of use and a second direction of use opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is greater than an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

Still another aspect of the present disclosure presents a method of making an abrasive article, including providing an extrudate containing a molten polymer; extruding the extrudate through a die to form a plurality of bristles, wherein the bristles comprise a plurality of abrasive particles; attaching the plurality of bristles to a circular center member having an outer edge and a radial line; wherein the bristles extending outward from the outer edge at a slant angle relative to the corresponding radial line.

Still another aspect of the present disclosure presents a robotic abrading system, including an abrasive article configured to abrade a workpiece, wherein the abrasive article comprises a circular center member having an outer edge and a radial line; a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member, wherein the bristles comprise a plurality of abrasive particles; wherein at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line; a tool configured to drive the abrasive article; and a force control, wherein the force control is configured to drive the tool.

Still another aspect of the present disclosure presents a robotic abrading system, including an abrasive article configured to abrade a workpiece, a tool configured to drive rotation of the abrasive article against the workpiece such that the abrasive article abrades the workpiece, a robotic device configured to urge the tool toward the workpiece; and the abrasive article comprising: a circular center member having an outer edge; a plurality of extruded bristles extending outward from the outer edge of the circular center member; wherein the abrasive article has a first direction of use, comprising the tool rotating in a first direction, and a second direction of use, comprising the tool rotating in a second direction opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is greater than an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

Still a further aspect of the present disclosure presents a method of abrading a workpiece using the abrasive article, the method including contacting the abrasive article with the workpiece with an applied force, wherein the abrasive bristle comprises; a circular center member having a radial line and extruded bristles extending outward from the circular center member at a slant angle in a slant direction relative to the corresponding radial line; moving at least one of the abrasive article and the workpiece, wherein the abrasive article has a direction of rotation relative to the workpiece, wherein the direction of rotation is opposite to the slant direction; removing a portion of material of the workpiece.

As used herein and in the appended claims:

The term “radial line” refers to a virtual line that passes through the center of a circle.

The term “radial plane” refers to a virtual plane along a radial line of a circular or cylindrical shape. Herein, the radial plane of a center member is perpendicular to the axis that the center member rotates around.

The term “extruded” refers to being formed through extrusion, which is a process of pushing material through a die of a desired cross-section.

The term “thermoplastic material” refers to a material that softens and flows upon application of pressure and heat.

The term “thermoplastic elastomer” (or “TPE”) refers to a material that, upon heating above the melting temperature of the hard regions, form a homogeneous melt which can be processed by thermoplastic techniques, such as extrusion, injection molding, blow molding, and the like; and subsequent cooling leads again to segregation of hard and soft regions resulting in a material having elastomeric properties.

The term “formed abrasive particles” generally refers to abrasive particles having at least a partially replicated shape.

The words “preferred” and “preferably” refer to embodiments described herein that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful, and is not intended to exclude other embodiments from the scope of the disclosure.

Relative terms such as left, right, forward, rearward, top, bottom, side, upper, lower, horizontal, vertical, and the like may be used herein and, if so, are from the perspective observed in the particular figure. These terms are used only to simplify the description, however, and not to limit the scope of the disclosure in any way.

Reference throughout this specification to “one embodiment,” “certain embodiments,” “one or more embodiments” or “an embodiment” means that a particular feature, structure, material, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. Thus, the appearances of the phrases such as “in one or more embodiments,” “in certain embodiments,” “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily referring to the same embodiment of the disclosure. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments.

These and other aspects of the present disclosure will be apparent from the detailed description below. In no event, however, should the above summaries be construed as limitations on the claimed subject matter, which subject matter is defined solely by the attached claims, as may be amended during prosecution.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. 1 is a schematic top view of an exemplary abrasive article according to prior art.

FIG. 2 is a schematic top view of an exemplary abrasive article according to an embodiment of the present disclosure.

FIGS. 3A-3C illustrate schematic sectional views taken along line 3-3 of FIG. 2, illustrating a side view of exemplary abrasive articles according to embodiments of the present disclosure.

FIG. 4 is a schematic perspective view of an exemplary abrasive article according to embodiments of the present disclosure.

FIGS. 5A-5D are schematic cross-sectional view of various embodiments of the bristle in an exemplary abrasive article according to some embodiments of the present disclosure.

FIG. 6 is a partial plan view of a segment of an exemplary abrasive article according to embodiments of the present disclosure in operation.

FIG. 7 illustrates the components that may be included in an exemplary robotic abrading system according to embodiments of the present disclosure.

FIG. 8 is a schematic view of an exemplary robotic abrading system according to embodiments of the present disclosure.

FIG. 9 illustrates a method of abrading a work piece by an exemplary abrasive article according to embodiments of the present disclosure.

FIG. 10 is a photo of an abrasive article made in accordance with an Example.

FIG. 11 is a data graph of force/brush interference testing measurements performed in the Examples.

FIG. 12 is a data graph of cut performance test performed in the Examples.

FIG. 13 is a photo of a robotic abrading system in accordance with an Example.

FIGS. 14A-14E are schematic top views of exemplary abrasive articles according to embodiments of the present disclosure.

Repeated use of reference characters in the specification and drawings is intended to represent the same or analogous features or elements of the disclosure. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the disclosure. The figures may not be drawn to scale.

DETAILED DESCRIPTION

Abrasive articles having bristles have been used to polish, clean, and abrade a wide variety of substrates as workpieces. These articles, including bristle discs and brushes, typically have a plurality of bristles that contact the workpiece (or a substrate). Abrasive particles can be added to bristles to increase their abrasiveness. There are many manufacturing steps necessary to manufacture a conventional abrasive article having bristles which contain abrasive particles. A mixture of abrasive particles and a thermoplastic binder may be combined and then extruded to form a bristle. The bristle is then cut to the desired length. A plurality of these bristles are then mechanically combined to form an article. Optionally, a plurality of these articles may be installed on a center member or plate to form an abrasive bristle assembly article.

Examples of products having abrasive bristles include SCOTCH-BRITE Bristle Discs and Brushes (available from 3M Company, St. Paul, MN), which are available in various sizes and configurations for a variety of abrasive applications. Other configurations of abrasives brushes, bristle, and/or bristles are described in, for example, U.S. Pat. Nos. 5,045,091 (Abrahamson et al.); 5,233,719 (Young et al.); 5,400,458 (Rambosek); 5,679,067 and 5,903,951 (Ionta et al.); 5,427,595 (Pihl et al.); 5,460,883 (Barber et al.); 3,618,154 (Muhler et al.); and 3,233,272 (Pambello).

Many abrasive articles having bristles include a center member, and a plurality of bristles extending outwardly from the center member. FIG. 1 illustrates a schematic top view of an example of a conventional abrasive article having bristles 120. From the top view, the center member 140 is generally circular shaped, having an outer edge 142 and a radial line R 144. A plurality of bristles 120 are positioned outwardly from the outer edge 142 of the center member 140 and are extending radially along the radial line 144 of the center member 140, as seen from the top view.

According to an embodiment of the present disclosure, an abrasive article 200 having bristles is illustrated in FIG. 2. From the top view, the center member 240 can be generally circular shaped, having an outer edge 242 and a radial line 244. A plurality of bristles 220 may extend outwardly from the center member 240, each bristle having a first bristle end (i.e., the end of a bristle most proximal to the center member 240), a second bristle end (i.e., the end of a bristle most distal from the center member 240), and a length connecting the first bristle end to the second bristle end. There may be spaces between bristles. Alternatively, adjacent bristle 220 may adjoin one another, for example, at the first bristle ends. Each bristle also has a joint, defined as the point where the bristle begins to expose proximal to the outer edge 242. The joint of a bristle can be the same or different from the first bristle end. For each bristle, the corresponding radial line is the radial line R 244 passing through the joint of the bristle 220. From the top view of an abrasive article 200 according to the present disclosure, the bristles 220 are positioned at a slant angle α relative to the corresponding radial line R 244. The slant angle α can be nonorthogonal, can be larger than 0 degree and smaller than 90 degrees. The slant angle α can be in the range of 5 degrees to 80 degrees, preferably in the range of 10 degrees to 60 degrees, 15 degrees to 50 degrees, and more preferably in the range of 20 degrees to 45 degrees, although other angles may be used as desired.

FIGS. 3A-3C each illustrates a side view of an exemplary abrasive article 300, 301, 302, respectively, according to some embodiments of the present disclosure. In some embodiments of abrasive article 300, the bristles 320 are substantially coplanar with a radial plane of the center member 340 (FIG. 3A). A radial plane of a center member is a plane along a radial line of the center member and is perpendicular to the axis that the center member rotates around. In another embodiment (FIG. 3B) of abrasive article 301, the bristles 321 are oblique to a radial plane of the center member 341, and are at an oblique angle β relative to the radial plane. As illustrated in FIG. 3B, a radial plane is along a radial line of the center member and extending perpendicular to the page, each bristle intersects a respective radial plane at the joint of the bristle. The oblique angle β can be any desired angle, preferably up to about 90 degrees, more preferably between about 10 degrees and 60 degrees. In still another embodiment (FIG. 3C) of abrasive article 302, the bristles 322 can be oblique to a radial plane of the center member, at more than one oblique angles relative to the radial plane. In the illustrated example (FIG. 3C), a first plurality of bristles 322 are at oblique angle β1 relative to the radial plane, a second plurality of bristles 322 are at oblique angle β2 relative to the radial plane. Optionally, a third plurality of bristles 322 are at oblique angle β3 relative to the radial plane. Optionally, a fourth plurality of bristles 322 are coplanar with a radial plane.

In some embodiments, at least a portion of the plurality of the bristles are oblique relative to the radial plane of the center member. In the illustrated example shown in FIG. 4, the center member 440 is generally planar and circular. A radial plane of the center member 440 can be defined as x-y plane. Z-axis is perpendicular to x, y-axes and also perpendicular to the radial plane. An exemplary bristle 420 is oblique relative to the radial plane (x-y plane) of the center member can have a projection 422 on x-y plane. The corresponding radial line of the bristle 420 is the radial line R 444 on x-y plane passing through the joint of the bristle 420 (or the projection of the joint on x-y plane). The bristle 420 is oriented such that the projection 422 is at a slant angle α relative to the corresponding radial line R 444. The slant angle α can be in the range of 5 degrees to 80 degrees, preferably in the range of 10 degrees to 60 degrees, 15 degrees to 50 degrees, and more preferably in the range of 20 degrees to 45 degrees, although other angles may be used as desired.

In some embodiments, at least a portion of the plurality of the bristles can have more than one slant angle for each of these bristles. In some embodiments, at least a portion of the plurality of the bristles can have slant angles varying along the length of a bristle. FIGS. 14A-14E illustrate schematic top views of some exemplary abrasive articles. In the illustrated example FIG. 14A, a bristle 1420 projects outwardly from the center member 1440, having a portion of the bristle along the corresponding radial line R 1444 and a portion of the bristle at a slant angle α relative to the corresponding radial line R 1444. In the illustrated example FIG. 14B, a bristle 1420 projects outwardly from the center member 1440, having a portion of the bristle at a slant angle α1 relative to the corresponding radial line R 1444 and a portion of the bristle at a slant angle α2 relative to the corresponding radial line R 1444, wherein α1 and α2 are not the same. In the illustrated example FIG. 14C, a bristle 1420 projects outwardly from the center member 1440, having a portion of the bristle at a slant angle α1 relative to the corresponding radial line R 1444, a portion of the bristle at a slant angle α2 relative to the corresponding radial line R 1444, and a portion of the bristle at a slant angle α3 relative to the corresponding radial line R 1444, wherein α1, α2 and α3 are not the same. In the illustrated example FIG. 14D, a bristle 1420 projects outwardly from the center member 1440, having a straight portion of the bristle and a curved portion of the bristle, thus the slant angle varies along the length of the bristle 1420. In the illustrated example FIG. 14E, a curved bristle 1420 projects outwardly from the center member 1440, thus the slant angle varies along the length of the bristle 1420.

Abrasive articles having bristles according to the present disclosure can have various structures, components, and compositions. The materials and article configuration will depend upon the desired abrading application. As used herein, the term "abrading" can include at least one of the following: remove a portion of a workpiece surface; impart a surface finish to a workpiece; descale a surface; deburr a surface; clean a workpiece surface, including removing paint or other coatings, gasket material, corrosion, oil residue, or other foreign material or debris; or some combination of the foregoing. In some applications, it may be preferred to provide aggressive abrasive characteristics, in which case the article may comprise abrasive particles, larger size abrasive particles, harder abrasive particles, a higher abrasive particle to binder ratio, or some combination of the above. In other applications, it may be preferred to provide a polish type finish to the surface being refined, or to clean a surface without removing surface material itself, in which case the article may employ smaller abrasive particles, softer abrasive particles, lower abrasive particle to binder ratio, or some combination of the above. It is possible to employ abrasive particles of varied composition and hardness to obtain the desired abrading characteristics, as well as blends of various abrasive particles.

Center Member

In some embodiments, a center member is a continuous circumferential portion which is generally planar. A center member can also be a contoured or curved hub. For example, a center member may be convex, concave, or conical in shape. A center member may be, for example, conical, with the bristles extending parallel to the conical surface defined by the center member.

The center member can have a various thickness. For example, the center member can have a thickness of above about 0.5 millimeter (mm), above about 1.0 mm, above about 3 mm, above about 10 mm, or above about 25 mm. Center member may be circular as illustrated in FIG.FIG. 2. The diameter of the outer edge of center member can vary, preferably in a range of from about 2.5 to 61.0 cm (1.0 to 24.0 inches), although smaller or larger center members are also within the scope of the disclosure. In some embodiments, the center member is of a suitable material and thickness to provide a flexible center member, which helps maintain more bristles in contact with an uneven or irregular workpiece. The center member preferably is capable of flexing at least 10°, more preferably at least 20°, and still more preferably at least 45° without damage or substantial permanent deformation to the hub. Center member shapes other than circular are also within the scope of the disclosure, including, but not limited to, oval, rectangular, square, triangular, diamond, and other polygonal shapes, as are relatively rigid or inflexible hubs.

A center member may be made of metals or polymeric materials. A polymeric cast center member can be formed by employing an epoxy or other resin in a mold.

A center member can be fabricated so that abrasive bristles can be employed in the form of abrasive brushes. A center member can include base plates, slots, spacers, or other suitable structural accessories to facilitate the attachment of abrasive bristles.

An abrasive article according to the present disclosure may optionally have an attachment mechanism on center member, such as a channel, keyway, or a root to mechanically join several articles together on a drive mechanism (e.g., a shaft) to provide an abrasive assembly. A center member may include one or more mounting holes, through which a locking rod and/or shaft may be inserted. Shaft and/or locking rod(s) may then be attached to a suitable rotary drive mechanism.

Bristles

Abrasive bristles may have any cross-sectional area, including but not limited to, circular, star, half moon, quarter moon, oval, rectangular, square, triangular, diamond, or other polygonal shape. For example, cross-sectional area of a bristle 520 can be shaped as illustrated in FIGS. 5A, 5B, 5C, and/or 5D.

In some embodiments, bristles 520 included in one single abrasive article may have the same cross-sectional shape and same cross-sectional area. A bristle 520 comprise a cross section of constant nominal diameter along their length, although it is possible that the exact diameter of the cross section of an actual bristle may fluctuate slightly along the bristle length based on the position of abrasive particles in the fiber. In some embodiments, bristles 520 included in one abrasive article may have various cross-sectional shapes or areas. Bristles 520 having different cross-sectional shapes, areas, and bristle lengths could be combined into a single abrasive article.

Bristles 520 comprise an aspect ratio defined as the length of bristle measured from first bristle end to the second bristle end, divided by the width of the bristle. In the case of an actual bristle with varying width, the width is defined as the average width along the length for purposes of determining the aspect ratio. In the case of non-circular cross section, the width is taken as the longest width in a given plane, such as the corner-to-corner diagonal of a square cross section. The aspect ratio of bristles is preferably at least 2, more preferably from about 5 to 100, and still more preferably from about 50 to 75. The size of bristles can be selected for the particular application of the abrasive article. The length of bristles is preferably from about 0.2 to 50 centimeters (cm), more preferably from about 1 to 25 cm, and still more preferably from about 5 to 15 cm. The width of the bristles is preferably from about 0.25 to 10 mm more preferably from about 0.5 to 5.0 mm, still more preferably about 0.75 to 3.0 mm, and most preferably from about 1.0 to 2.0 mm. The width of bristles can be the same as or different from the thickness of center member. In one preferred embodiment, all of the bristles may have the same dimensions. Alternatively, bristles on an abrasive article including a plurality of bristles may have different dimensions such as different lengths, widths or cross-sectional areas. For example, an abrasive article may have two groups of short bristles and two groups of long bristles, similar to what is shown in FIG.FIG. 9 of U.S. Pat. No. 5,903,951 (Ionta et al.). Moreover, it is possible to arrange ring sector segments, each having bristles of different length. With respect to the abrasive assembly having bristles, it is possible to employ adjacent articles having different bristles.

The density and arrangement of bristles can be chosen for the particular application of an abrasive article. Bristles may be arranged uniformly around the outer edge of center member. Alternatively, bristles can be arranged in groups with spaces between the groups. Accordingly, an abrasive article may have a portion of outer edge which does not include any bristles. The bristles may be present over only a portion of outer edge of the center member, or substantially over the entire outer edge.

The material, length, and configuration of the bristles are preferably chosen such that bristles are sufficiently flexible to aid in refining uneven or irregular workpieces. The bristles are preferably capable of bending at least 25°, more preferably at least 45°, still more preferably at least 90°, and most preferably about 180°, without damage or substantial permanent deformation to the bristles.

It is possible to reinforce the bristles with any suitable structure. For example, it is possible to include a bristle having a reinforcing wire or fiber embedded within it.

The bristles according to the present disclosure may comprise a thermoplastic material. Examples of suitable thermoplastic materials include polymers such as polycarbonate, polyetherimide, polyester, polyethylene, polysulfone, polystyrene, polybutylene, acrylonitrile-butadiene-styrene block copolymer, polypropylene, acetal polymers, polyurethanes, polyamides, and combinations thereof. In general, preferred thermoplastic materials of the disclosure are those having a high melting temperature and good heat resistance properties. Thermoplastic materials may be preferably employed for low-speed applications of article, in which stress during operation is relatively low. Examples of commercially available thermoplastic materials suitable for use with the present disclosure include GRILON CR9 copolymer of NYLON 6,12 available from EMS-American Grilon, Inc., Sumter, South Carolina.

One particular thermoplastic material suitable for use with the present disclosure is a polyamide resin material, which is characterized by having an amide group, i.e., --C(O)NH--. Various types of polyamide resin materials, i.e., NYLONS can be used, such as NYLON 6/6 or NYLON 6. NYLON 6/6 is a condensation product of adipic acid and hexamethylenediamine. NYLON 6/6 has a melting point of about 264° C. and a tensile strength of about 770 kg/cm2. NYLON 6 is a polymer of ε-caprolactam. NYLON 6 has a melting point of about 220° C. and a tensile strength of about 700 kg/cm2. Examples of commercially available NYLON resins useable in articles according to the present disclosure include “VYDYNE” from Ascend Performance

Materials, Houston, TX. “ZYTEL” and “MINION” both from Du Pont, Wilmington, Del. “TROGANMID” from Evonik, Allentown, PA, and “ULTRAMID” from BASF Corp., Parsippany, N.J.

In some instances, the material of the bristle includes an extruded thermoplastic elastomer. The term “thermoplastic elastomer” (or “TPE”) refers to a material that, upon heating above the melting temperature of the hard regions, form a homogeneous melt which can be processed by thermoplastic techniques, such as extrusion, injection molding, blow molding, and the like; and subsequent cooling leads again to segregation of hard and soft regions resulting in a material having elastomeric properties. Thermoplastic elastomers are defined and reviewed in *Thermoplastic Elastomers, A Comprehensive Review*, edited by N.R. Legge, G. Holden and H. E. Schroeder, Hanser Publishers, New York, 1987 (referred to herein as “Legge et al.”, the entire disclosure of which is incorporated by reference herein). Thermoplastic elastomers (as used herein) are generally the reaction product of a low equivalent weight polyfunctional monomer and a high equivalent weight polyfunctional monomer, wherein the low equivalent weight polyfunctional monomer has a functionality of at most about 2 and equivalent weight of at most about 300 and is capable on polymerization of forming a hard segment (and, in conjunction with other hard segments, crystalline hard regions or domains) and the high equivalent weight polyfunctional monomer has a functionality of at least about 2 and an equivalent weight of at least about 350 and is capable on polymerization of producing soft, flexible chains connecting the hard regions or domains. “Thermoplastic elastomers” differ from “thermoplastics” and “elastomers” (a generic term for substances emulating natural rubber in that they stretch under tension, have a high tensile strength, retract rapidly, and substantially recover their original dimensions).

Extruded abrasive bristles including thermoplastic elastomer compositions exhibit much higher abrading efficiency (weight of workpiece removed per weight of bristle wear) and longer flex fatigue life when compared with other abrasive bristles. The benefits of extruded abrasive bristles including thermoplastic elastomers include, but not limited to, the ease of processability of thermoplastic elastomers combined with hard rubber characteristics, excellent binding to abrasive particles and improved cutting performance. The benefits are especially advantageous for high speed, high stress abrading applications.

Thermoplastic elastomers combine the proccessability (when molten) of thermoplastic materials with the functional performance and properties of conventional thermosetting rubbers (when in their non-molten state), and which are described in the art as ionomeric, segmented, or segmented ionomeric thermoplastic elastomers. The segmented versions comprise “hard segments” which associate to form crystalline hard domains connected together by “soft”, long, flexible polymeric chains. The hard domain has a melting or disassociation temperature above the melting temperature of the soft polymeric chains.

Commercially available thermoplastic elastomers include segmented polyester thermoplastic elastomers, segmented polyurethane thermoplastic elastomers, segmented polyamide thermoplastic elastomers, blends of thermoplastic elastomers and thermoplastic materials, and ionomeric thermoplastic elastomers.

“Segmented thermoplastic elastomer”, as used herein, refers to the sub-class of thermoplastic elastomers which are based on polymers which are the reaction product of a high equivalent weight polyfunctional monomer and a low equivalent weight polyfunctional monomer. Segmented thermoplastic elastomers are preferably the condensation reaction product of a high equivalent weight polyfunctional monomer having an average functionality of at least 2 and an equivalent weight of at least about 350, and a low equivalent weight polyfunctional monomer having an average functionality of at least about 2 and an equivalent weight of less than about 300. The high equivalent weight polyfunctional monomer is capable on polymerization of forming a soft segment, and the low equivalent weight polyfunctional monomer is capable on polymerization of forming a hard segment. Segmented thermoplastic elastomers useful in the present disclosure include polyester TPEs, polyurethane TPEs, and polyamide TPEs, and silicone elastomer/polyimide block copolymeric TPEs, with the low and high equivalent weight polyfunctional monomers selected appropriately to produce the respective TPE. The segmented TPEs preferably include “chain extenders”, low molecular weight (typically having an equivalent weight less than 300) compounds having from about 2 to 8 active hydrogen functionality, and which are known in the TPE art. Chain extenders are typically used in segmented thermoplastic elastomers to increase the hard segment and hard domain size and thus provide one mechanism to alter the physical properties of the resultant segmented TPE. Particularly preferred examples include ethylene diamine and the linear glycols such as ethylene glycol, 1,4-butanediol, 1,6-hexanediol, and hydroquinone bis(2-hydroxyethyl) ether.

The mechanical properties of segmented thermoplastic elastomers (such as tensile strength and elongation at break) are dependent upon several factors. The proportion of the hard segments in the polymers which form the TPEs, their chemical composition, their molecular weight distribution, the method of preparation, and the thermal history of the TPE all affect the degree of hard domain formation. Increasing the proportion of the low equivalent weight polyfunctional monomer tends to increase the hardness and the modulus of the resultant TPE while decreasing the ultimate elongation.

“Ionomeric thermoplastic elastomers” refers to a sub-class of thermoplastic elastomers based on ionic polymers (ionomers). Ionomeric thermoplastic elastomers are composed of two or more flexible polymeric chains bound together at a plurality of positions by ionic associations or clusters. The ionomers are typically prepared by copolymerization of a functionalized monomer with an olefinic unsaturated monomer, or direct functionalization of a preformed polymer. Carboxyl-functionalized ionomers are obtained by direct copolymerization of acrylic or methacrylic acid with ethylene, styrene and similar comonomers by free-radical copolymerization. The resulting copolymer is generally available as the free acid, which can be neutralized to the degree desired with metal hydroxides, metal acetates, and similar salts. A review of ionomer history and patents concerning same is provided in Legge et al., pages 231-243.

"Thermoplastic material", or "TP" as used herein, has a more limiting definition than the general definition, which is "a material which softens and flows upon application of pressure and heat." It will of course be realized that TPEs meet the general definition of TP, since TPEs will also flow upon application of pressure and heat. It is thus necessary to be more specific in the definition of "thermoplastic" for the purposes of this disclosure. "Thermoplastic" as used herein, means a material which flows upon application of pressure and heat, but which does not possess the elastic properties of an elastomer when below its melting temperature.

Blends of TPE and TP materials are also within the disclosure, allowing even greater flexibility in tailoring mechanical properties of the abrasive bristles of the disclosure.

Commercially available and preferred segmented polyesters include those known under the trade designations "HYTREL 4056", "HYTREL 5526", "HYTREL 5556", "HYTREL 6356", "HYTREL 7246", and "HYTREL 8238" available from E.I.DuPont de Nemours and Company, Inc., Wilmington, Del., with the most preferred including HYTREL 5526, HYTREL 5556, and HYTREL 6356. A similar family of thermoplastic polyesters is available under the tradename "RITEFLEX" (Hoechst Celanese Corporation). Still further useful polyester TPEs are those known under the trade designations "ECDEL" from Eastman Chemical Products, Inc., Kingsport, Tennessee. "ARNITEL" from DSM Engineered Plastics; and "BEXLOY" from Du Pont. Further useful polyester TPEs include those available as "LUBRICOMP" from SABIC, Exton, Pa., and is commercially available incorporating lubricant, glass fiber reinforcement, and carbon fiber reinforcement.

Commercially available segmented polyamides include those known under the trade designation "PEBAX" and "RILSAN" both available from Arkema, King of Prussia, PA.

Commercially available segmented polyurethanes include those known under the trade designation "ESTANE", available from Lubrizol, Brecksville, Ohio. Other segmented polyurethanes include those known under the trade designations "PELLETHANE", and "ISOPLAST" from The Dow Corning Company, Midland, Michigan; and those known under the trade designation "ELASTOLLAN" from BASF Corporation.

Thermoplastic elastomers are further described in U.S. Pat. No. 5,427,595 (Pihl et al.), and assigned to the assignee of the present disclosure, the entire disclosure of which is incorporated herein by reference.

Bristles also include a plurality of abrasive particles. The abrasive particles may be dispersed throughout a bristle, or are present at least in a portion of a bristle. Preferably, abrasive particles are present at least in a portion of a bristle close to the second bristle end (i.e., the end of a bristle most distal from the center member) that is opposite to the first bristle end. Abrasive particles can also be present close to the surface of a bristle, such that they can interact with a workpiece during an abrading operation. The abrasive particles should have sufficient hardness and surface roughness to function as abrasive particles in abrading processes. Preferably, the abrasive particles have a Mohs hardness of at least 4, at least 5, at least 6, at least 7, or even at least 8.

The abrasive particles can include, for example, fused aluminum oxide, heat-treated aluminum oxide, white fused aluminum oxide, ceramic aluminum oxide materials such as those commercially available as 3M CERAMIC ABRASIVE GRAIN from 3M Company, St. Paul, Minnesota, brown aluminum oxide, blue aluminum oxide, silicon carbide (including green silicon carbide), titanium diboride, boron carbide, tungsten carbide, garnet, titanium carbide, diamond, cubic boron nitride, garnet, fused alumina zirconia, iron oxide, chromia, zirconia, titania, tin oxide, quartz, feldspar, flint, emery, sol-gel-derived ceramic (e.g., alpha alumina), and combinations thereof. Examples of sol-gel-derived abrasive particles from which the abrasive particles can be isolated, and methods for their preparation can be found, in U. S. Pat. Nos. 4,314,827 (Leitheiser et al.); 4,623,364 (Cottringer et al.); 4,744,802 (Schwabel), 4,770,671 (Monroe et al.); and 4,881,951 (Monroe et al.). It is also contemplated that the abrasive particles could comprise abrasive agglomerates such, for example, as those described in U. S. Pat. Nos. 4,652,275 (Bloecher et al.) or 4,799,939 (Bloecher et al.). In some embodiments, the abrasive particles may be surface-treated with a coupling agent (e.g., an organosilane coupling agent) or other physical treatment (e.g., iron oxide or titanium oxide) to enhance adhesion of the crushed abrasive particles to the binder. The abrasive particles may be treated before combining them with the binder, or they may be surface treated in situ by including a coupling agent to the binder.

Preferably, the abrasive particles include ceramic abrasive particles such as, for example, sol-gel-derived polycrystalline alpha alumina particles. Ceramic abrasive particles composed of crystallites of alpha alumina, magnesium alumina spinel, and a rare earth hexagonal aluminate may be prepared using sol-gel precursor alpha alumina particles according to methods described in, for example, U. S. Pat. No. 5,213,591 (Celikkaya et al.) and U. S. Publ. Pat. Appl. Nos. 2009/0165394 A1 (Culler et al.) and 2009/0169816 A1 (Erickson et al.). Further details concerning methods of making sol-gel-derived abrasive particles can be found in, for example, U. S. Pat. Nos. 4,314,827 (Leitheiser); 5,152,917 (Pieper et al.); 5,435,816 (Spurgeon et al.); 5,672,097 (Hoopman et al.); 5,946,991 (Hoopman et al.); 5,975,987 (Hoopman et al.); and 6,129,540 (Hoopman et al.); and in U. S. Publ. Pat. Appl. No. 2009/0165394 Al (Culler et al.). Abrasive particles can be of inorganic materials (such as ceramic) or organic materials. A type of useful abrasive particles including organic materials is disclosed in U.S. Pat. Application No. 20210122959 (Mevissen et al.), the disclosure of which is incorporated herein by reference.

Abrasive particles can include crushed abrasive particles, formed abrasive particles, and/or precisely formed abrasive particles.

Useful crushed abrasive particles may be the result of a crushing operation (e.g., crushed abrasive particles that have been sorted for shape and size) or the result of a shaping operation (i.e., shaped abrasive particles) in which an abrasive precursor material is shaped (e.g., molded), dried, and converted to ceramic material. Combinations of abrasive particles resulting from crushing with abrasive particles resulting from a shaping operation may also be used. The abrasive particles may be in the form of, for example, individual particles, agglomerates, composite particles, and mixtures thereof.

In some preferred embodiments, the abrasive particles may be formed abrasive particles. As used herein, the term “formed abrasive particles” generally refers to abrasive particles (e.g., formed ceramic abrasive particles) having at least a partially replicated shape. Useful abrasive particles may be formed abrasive particles can be found in U. S. Pat. Nos. 5,201,916 (Berg); 5,366,523 (Rowenhorst (Re 35,570)); and 5,984,988 (Berg). U. S. Pat. No. 8,034,137 (Erickson et al.) describes alumina abrasive particles that have been formed in a specific shape, then crushed to form shards that retain a portion of their original shape features.

Formed abrasive particles also include precisely formed abrasive particles. As used herein, the term “precisely formed abrasive particles” generally refers to abrasive particles with at least a portion of the abrasive particles having a predetermined shape that is replicated from a mold cavity used to form the shaped precursor abrasive particle. Examples of precisely formed abrasive particles include CUBITRON II (available from 3M Company, St. Paul, Minnesota). Examples of precisely formed abrasive particles and details concerning such abrasive particles and methods for their preparation can be found, for example, in U. S. Pat. Nos. 8,142,531 (Adefris et al.); 8,142,891 (Culler et al.); 8,142,532 (Erickson et al.); 9,771,504 (Adefris); and in U. S. Pat. Appl. Publ. Nos. 2012/0227333 (Adefris et al.); 2013/0040537 (Schwabel et al.); 2013/0125477 (Adefris); and 2015/0267097 (Rosenflanz et al.). One particularly useful precisely formed abrasive particle can be triangular-prism shaped or shaped as a platelet having three-sidewalls, any of which may be straight or concave, and which may be vertical or sloping with respect to the platelet base; for example, as set forth in the above cited references. Other abrasive particles, such as platey, or partially shaped particles can also be used.

The abrasive particles may include a surface coating. Such surface coating can be a coating as described in, for example, U. S. Pat. Nos. 5,352,254 (Celikkaya); 5,213,591 (Celikkaya et al.); 5,011,508 (Wald et al.); 1,910,444 (Nicholson); 3,041,156 (Rowse et al.); 5,009,675 (Kunz et al.); 5,085,671 (Martin et al.); 4,997,461 (Markhoff-Matheny et al.); and 5,042,991 (Kunz et al.).

In some embodiments, the abrasive particles may be selected to have a length and/or width in a range of from 0.1 micrometers to 3.5 millimeters (mm), more typically 0.05 mm to 3.0 mm, and more typically 0.1 mm to 2.6 mm, although other lengths and widths may also be used.

The abrasive particles may be selected to have a thickness in a range of from 0.1 micrometer to 1.6 mm, more typically from 1 micrometer to 1.2 mm, although other thicknesses may be used. In some embodiments, abrasive particles may have an aspect ratio (length to thickness) of at least 2, 3, 4, 5, 6, or more.

In some embodiments, at least a portion of abrasive particles contained in the bristles are orientationally aligned. For example, at least 30%, 50%, 60%, 70%, 80%, or 90% of abrasive particles contained in the bristles are orientationally aligned. Preferably, the orientationally aligned abrasive particles are formed abrasive particles. The formed abrasive particles can be present at an orientation such that a tip of a formed abrasive particle points outwards, thus the tip may efficiently interact with a workpiece during an abrading operation. Such an orientation of abrasive particles can provide better abrasive performance, such as higher cut, better finish, and/or longer life of the abrasive article. An example of an abrasive article having bristles with orientationally aligned abrasive particles is disclosed in PCT Pat. Publication No. WO 2020/084382 (Holmes et al.).

Abrasive bristles can optionally further include additives, such as, for example, fillers (including grinding aids), fibers, antistatic agents, antioxidants, processing aids, UV stabilizers, flame retardants, lubricants, wetting agents, surfactants, pigments, dyes, coupling agents, plasticizers, and suspending agents. The amounts of these materials are selected to provide the properties desired.

For some refining applications, it is preferred that the bristles include a lubricant. The presence of a lubricant reduces the friction of the bristle contacting the workpiece surface. This reduces the heat generated when refining the workpiece. Excessive heat may cause the brush segment to leave residue or smear on the workpiece or to otherwise harm the workpiece. Suitable lubricants include lithium stearate, zinc stearate, calcium stearate, aluminum stearate, ethylene bis stearamide, graphite, molybdenum disulfide, triglyceride ester, polytetraflouroethylene (PTFE), and silicone compounds, for example useful with thermoplastic elastomers.

The bristles may include a coupling agent to improve the bond between the binder and the abrasive particles as is known in the art. Examples of such coupling agents suitable for this invention include organosilanes, zircoaluminates and titanates.

The bristles may include a filler. Examples of useful fillers for this invention include: metal carbonates (such as calcium carbonate (chalk, calcite, marl, travertine, marble and limestone), calcium magnesium carbonate, sodium carbonate, magnesium carbonate), silica (such as quartz, glass beads, glass bubbles and glass fibers), silicates (such as talc, clays, (montmorillonite) feldspar, mica, calcium silicate, calcium metasilicate, sodium aluminosilicate, sodium silicate), metal sulfates (such as calcium sulfate, barium sulfate, sodium sulfate, aluminum sodium sulfate, aluminum sulfate), gypsum, vermiculite, wood flour, aluminum trihydrate, carbon black, metal oxides (such as calcium oxide (lime), aluminum oxide, titanium dioxide), and metal sulfites (such as calcium sulfite). In some instances, the filler may serve as an abrasive particle.

The bristles may further include a grinding aid. A grinding aid is a particulate material that the addition of which has a significant effect on the chemical and physical processes of abrading which results in improved performance. In particular, it is believed in the art that the grinding aid will either decrease the friction between the abrasive particles and the workpiece being abraded, prevent the abrasive particle from "capping", i.e. prevent metal particles from becoming welded to the tops of the abrasive particles, decrease the interface temperature between the abrasive particles the workpiece, or decrease the grinding forces. Examples of chemical groups of grinding aids include waxes, organic halide compounds, halide salts and metals and their alloys.

Attachment Mechanism

Abrasive article may include an attachment mechanism to attach the abrasive article to a power tool, as generally shown and described, for example, in U.S. Pat. Nos. 5,903,951 (Ionta et al.); 5,427,595 (Pihl et al.). For example, several articles may be joined together to form an assembly as described therein, and/or one or more articles may be attached to a support mechanism such as a separate center member or shaft as described therein. Center member may include an inner edge configured to engage with such a shaft, and/or may also (or alternatively) include mounting holes for accepting one or more locking rods. Center member may include a channel or keyway configured to engage a suitably configured key in a shaft. As further described therein, center member may be continuous, and not include an opening defined by an inner edge. An attachment mechanism may be provided at the center of center member. This type of attachment mechanism is suitable for use with 360° circular articles. Suitable attachment mechanisms are described in, for example, U.S. Pat. Nos. 3,562,968; 3,667,170; and 3,270,467, the entire disclosures of all of which are incorporated herein by reference.

In some embodiments, a hook and loop type attachment can be used to attach the abrasive article to a tool, such as a power rotary tool. Suitable hook-and loop fasteners, for example, can include those disclosed in U.S. Pat. No. 5,077,870 (Melbye et al.), incorporated herein by reference, or of the type commercially available as SCOTCHMATE from 3M Company (St. Paul, Minnesota). It is also possible to use a hermaphroditic fastener such as DUAL LOCK fastener, available from 3M Company, to secure the abrasive article to a backup pad. It is also possible to employ intermeshing structured surfaces, such as disclosed in U.S. Pat. No. 4,875,259 (Appeldorn), incorporated herein by reference.

It is also within the scope of the present disclosure to use an attachment system includes a layer of adhesive, for example, pressure sensitive adhesive. An abrasive article or its accessories can include a surface to which the pressure sensitive adhesive may releasably attach with the desired attachment strength. Examples of suitable pressure sensitive adhesives include latex crepe, rosin, acrylic polymers and copolymers such as polybutylacrylate and polyacrylate ester, vinyl ethers such as polyvinyl n-butyl ether, alkyd adhesives, rubber adhesives such as natural rubber, synthetic rubber, chlorinated rubber, and mixtures thereof. The adhesive is selected to provide the desired attachment characteristics. One preferred surface to which the abrasive may be releasably affixed is a vinyl sheet.

Alternatively, the center member of an abrasive article may contain one or more straight or threaded holes or openings so that the abrasive article may be mechanically secured (such as with a bolt and nut). Such a hole may optionally be fitted with an insert of a different material from that of the center member of the abrasive article.

The abrasive article may further include optional reinforcing mechanism which can contain a fiber reinforcing substrate. Reinforcing can include, for example, fabric, non-woven sheeting, mat, mesh, scrim, and the like, or can include individual fibers dispersed throughout the article. The reinforcing mechanism may optionally contain a treatment to modify its physical properties. The purpose of the reinforcing mechanism is to increase the flexural strength and tensile strength of the article. Examples of reinforcing fibers suitable for use in the present disclosure include glass fibers, metal fibers, carbon fibers, wire mesh, mineral fibers, fibers formed of heat resistant organic materials, or fibers made from ceramic materials. Ether organic fibers include polyvinyl alcohol fibers, nylon fibers, polyester fibers and phenolic fibers. If glass fibers are used, the polymer mixture may preferably contain a coupling agent, such as a silane coupling agent, to improve the adhesion to the thermoplastic material.

Method of Making Abrasive Articles

Abrasive bristles in accordance with the present disclosure are made by an extrusion process. In some embodiments, the extrusion process includes the use of at least one extruder, the outlet of which connected to a die. The extrudate includes a molten, organic polymeric material, which may include a TPE or TP (or a blend of TPE and TP), and can be adapted to form one bristle component.

Abrasive particles, along with optional additives, such as coupling agents, fillers, pigments, and the like, can be added to the molten organic polymeric materials upstream of the die. One or more abrasive bristle precursors are formed from the extrudate(s) by cooling the extrudate(s) (preferably by quenching in a cooling water bath or flowing stream of cooling water) to a temperature sufficient to harden the molten organic polymeric materials. The abrasive bristle precursors are then typically wound onto suitable cores by winding machines well known in the art, where they are held until cut into individual abrasive bristles.

Abrasive particles may also be applied to an abrasive bristle precursor extrudate by projecting the abrasive grains toward the extrudate by force, such as electrostatic or mechanical force. Alternatively, the abrasive particles may be applied via a fluidized bed of the abrasive particles wherein the extrudate passes through the fluidized bed. Preferably, the molten organic polymeric materials are passed through a die having abrasive particles already therein, and the extrudate cooled to form the abrasive bristle precursors.

In the preferred method in accordance with the disclosure, an extruder (or other melt rendering apparatus, such as heated vessels) can heat the organic polymeric materials above the hard domain or ionic cluster melting or dissociation temperature of the TPE employed (which may have a range that can change with type and grade of the TPE) and the melting temperature of TP employed (which may also have a temperature range) and push molten organic polymeric materials through a heated die.

Abrasive particles may be added to the molten organic materials through feed ports of the extruders, preferably at points early enough to afford adequate dispersal of abrasive particles throughout the molten organic materials but not cause undue abrasion of the metallic parts of the extruders or dies. Alternatively, abrasive particles may be deposited on the molten organic polymeric via a second step (for example, after forming the extrudate), such as by electrostatic coating.

The abrasive bristle precursors can be cooled in various suitable ways, for example, by using a cold water quench. A cold water quench can be located downstream (preferably immediately downstream) of the die through which the extrudate passes to achieve rapid cooling of the molten organic polymeric materials to form an abrasive bristle precursor including at least one of TP and TPE materials and abrasive particles.

After the abrasive bristle precursor has hardened, it may have an optional coating (for example, a plastic coating) applied thereover, for aesthetic, storage, or other purposes.

It should further be understood that the abrasive bristles and abrasive particles can contain fillers, lubricants, and grinding aids in levels typically used in the abrasives art.

The abrasive bristles may be incorporated into a wide variety of abrasive articles, either clumped together or attached to various substrates. In various embodiments, a plurality of abrasive bristles glued or otherwise attached to a center member using methods of attachment that are known in the art. One method of making abrasive articles having bristles can use a conventional "channel" brush-making machine, such as that sold under the trade designation "Model Y", available from Carlson Tool and Machine Company, Geneva, Illinois.

A center member may be made from metals or polymeric materials. To make a polymeric center member, a mold is typically fabricated so that abrasive filaments can be employed in the form of abrasive brushes. A round base plate can be fabricated with a predetermined diameter center through hole which is adapted to accept a solid, cylindrical core piece. Slots can be machined into one surface of the base plate to create a radial pattern so that thin metal spacers can be inserted therein. The slots can extend outwards to the periphery of the plate. The spacers may then be put in the slots. A plurality of abrasive bristles can be positioned and aligned within the spaces left between the spacers. The spacers provide a method to uniformly and closely distribute the abrasive bristles with a predetermined length. A clamp ring can be used to hold abrasive bristles firmly A polymeric cast center member can be formed by pouring a liquid epoxy or other resin into the center cavity formed between the solid, cylindrical center core piece and the clamp ring. One useful resin can include, for example, the two-part epoxy resin known under the trade designation “DP-420”, from 3M Company. After the resin is fully cured, the abrasive article can be ready for using or testing. More embodiments and details of making abrasive articles with bristles can be found in, for example, U.S. Pat. Nos. 5,045,091 (Abrahamson et al.); 5,233,719 (Young et al.); 5,400,458 (Rambosek); 5,679,067 and 5,903,951 (Ionta et al.); 5,427,595 (Pihl et al.); 5,460,883 (Barber et al.); 3,618,154 (Muhler et al.); and 3,233,272 (Pambello).

According to various embodiments of the present disclosure, a center member can be circular with a radial line, and at least a portion of the bristles can be positioned at a slant angle relative to the radial line. When attaching the bristles to the center member, the bristle orientation can be manipulated before the bristles are locked in positions attached to the center member. In some embodiments wherein a polymeric center member is employed, the bristle orientation can be manipulated prior to adding and solidifying a resin, for example, an epoxy or urethane resin, to the molded center member. The bristles can be positioned with respect to the point where a bristle exists the outer edge of the center member at a slant angle relative to the radial line of the center member. The slant angle can be nonorthogonal, can be larger than 0 degree and smaller than 90 degree. The slant angle can be in the range of 5 degrees to 80 degrees, preferably 10 degrees to 60 degrees, 15 degrees to 50 degrees, and more preferably 20 degrees to 45 degrees, although other angles may be used as desired.

Types of abrasive articles including bristles include wheel brushes, cylinder brushes (such as printed circuit cleaning brushes), mini-grinder brushes, floor scrubbing brushes, cup brushes, end brushes, flared cup end brushes, circular flared end cup brushes, coated cup and variable trim end brushes, encapsulated end brushes, pilot bonding brushes, tube brushes of various shapes, coil spring brushes, flue cleaning brushes, chimney and duct brushes, and the like. The bristles in any one abrasive article can be the same or different in construction, configuration, size, etc.

Method of Abrading a Workpiece

Abrasive articles of many types according to the present disclosure can be used in various applications, such as cleaning, deburring, imparting decorative finishes onto metal, plastic, and glass substrates, and like uses. Generally, abrading a workpiece includes removing a portion of a workpiece surface; imparting a surface finish to a workpiece; cleaning a workpiece surface, including removing paint or other coatings, gasket material, corrosion, or other foreign material; or some combination of the foregoing.

In some embodiments, an abrasive article having bristles can be fastened by the attachment mechanism to a shaft and/or a suitable drive mechanism. An abrasive article having bristles can be mounted to a suitable rotary drive mechanism, such as commercially available servo motors.

An abrasive article according to the present disclosure, for example, an abrasive disc having bristles, has a first direction of use, and a second direction of use that is opposite to the first direction of use (FIG. 9). For example, as illustrated in FIG. 6, an abrasive article 600 includes a plurality of bristles 620 that are slanted in a clockwise direction away from a radial line 644 of center member 640, starting from the outer edge 642 of the center member 640. The abrasive article 600 can rotate counterclockwise as a first direction of use (shown as direction 682) during abrading operation on a workpiece 690. This first direction of use 682 of the abrasive article 600 is opposite to the direction in which the plurality of bristles 620 are slanted away from the radial line 644. The abrasive article 600 can also rotate clockwise as a second direction of use (shown as direction 684) during abrading operation on a workpiece 690. This second direction of use 684 of the abrasive article 600 is consistent with the direction in which the plurality of bristles 620 are slanted away from the radial line 644. In various embodiments, while tested under the same testing conditions, an amount of material removed from a workpiece 690 when the abrasive article 600 is moved in the first direction of use 682 is different from an amount of material removed of a workpiece 690 when the abrasive article 600 is moved in the second direction 684. The amount of material removed from a workpiece 690 when the abrasive article 600 is moved in the first direction of use 682 can be greater than the amount of material removed of a workpiece 690 when the abrasive article 600 is moved in the second direction 684, by at least 5%, 10%, 15%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, or even 90%. The first direction of use can be a preferred direction of use of the abrasive article in such embodiments.

In some preferred embodiments, a method of abrading a workpiece using the abrasive article includes: contacting an abrasive article according to the present disclosure with a workpiece with an applied force, wherein the abrasive article includes extruded bristles extending outward from the center member at a slant angle in a slant direction relative to the radial line; moving at least one of the abrasive article and the workpiece such that the abrasive article has a direction of rotation relative to the workpiece, and the direction of rotation is opposite to the slant direction.

Abrading work can be operated either dry or wet, as with water, lubricant, rust inhibitor, or other suitable liquids as is well known in the art. An abrasive article having bristles can be rotated at any suitable speed, for example, in the range of about 50 to 15,000 revolutions per minute (RPM), although higher or lower speeds can be used as desired. It should be noted that the bristles can be sufficiently flexible and supple that, under many refining operations, contact of the bristle against the workpiece is along a substantial length of the side of the bristle, not merely a small portion of the bristle immediately adjacent the bristle ends, as illustrated in FIG. 6. An abrasive article containing organic abrasive particles can be used to remove a foreign material, for example, paint, dirt, debris, oil, oxide coating, rust, adhesive, gasket material and the like, from a workpiece surface without removing a significant amount of material from the workpiece itself.

Abrading operations can be performed with applying any suitable force on the abrasive article against a workpiece, for example, from about 0.1 to 200 kilograms (kg). In some embodiments, the applied force is predetermined to achieve a desirable result, based on various factors, such as applications, abrasive article selection, operating parameters, experience and knowledge of an operator, or references from a database. In some embodiments, the applied force is constant throughout the life of the abrasive article.

In some embodiments, the applied force can be modified and optimized in real time during an abrading operation. For example, with the addition of some advanced force sensing technologies, the applied force can be optimized based on the real-time parameters sensed or measured on or between abrasive tools, abrasive articles, and/or workpieces. Reactive control loops / algorithms can help determine and optimize controlled forces applied to a workpiece by, for example, a robotic manipulator. More examples of optimization of applied force, as well as other operation parameters, using "smart" or automation technologies of abrasive system can be found in, for example, U.S. Pat. Application Publication Nos. 2020/0030938 (Knudson et al.); 2020/0030936 (Knudson et al.); 2021/0308825 (Gabriel et al.); and PCT Pat. Application Publication No. WO 2020/084523 (Hemes et al.).

To apply and control the force of abrasive articles having bristles applied on a workpiece, the depth of interference between the bristles and the workpiece, referred as "interference depth" herein, is usually used as a force-controlling parameter. However, over the course of the abrasive article life, the bristles in abrasive articles are gradually worn, interference depth needs to be re-evaluated, and it requires intermittent brush diameter measurement to account for brush wear. This issue may cause frequent interruptions of abrading work, extra process steps and labor attention, and decrease the abrading efficiency.

It is unexpectedly found that an abrasive article having bristles according to the present disclosure can provide a characteristic that is responsive to an applied force. In particular, interference depth of the abrasive article exhibits consistent reaction to an applied force. Advantageously, the responsive characteristics provide better adaptability of the abrasive article to the force control and eliminate the needs for frequent abrasive wear monitoring.

It is also surprising to find that an abrasive article having bristles according to the present disclosure requires less power to perform an abrading operation. For example, it has been found that an abrasive article having bristles according to the present disclosure shows a significant reduction in motor capacity required to achieve a deburring operation.

Robotic Abrading System

This present disclosure also describes systems, methods and techniques related to various problems in robotic and automated abrasive applications. Material removal and subsequent polishing and conditioning are not trivial to automate with the key issue being that both process actions are inherently force-dependent. That is, they require precise applied forces during processing to obtain optimal (or even sufficient) results. Robotic abrading systems have been used for deburring operations involving abrasive articles having bristles. An abrasive article according to the present disclosure can provide a characteristic that is responsive to an applied force. In particular, interference depth of the abrasive article according to the present disclosure advantageously exhibits consistent reaction to force control. This advantage enables the better adaptability to the force control, especially in a robotic and automated abrading operation performed by a robotic abrading system, where a force control (compliance) is employed.

The present disclosure herein discloses robotic abrading systems involving abrasive articles having bristles and methods of using such robotic abrading systems that represent improvements on the current state of the art. In particular, the present disclosure discloses robotic abrading systems involving abrasive articles having bristles that show responsive characteristics adaptable to force control. Based on the responsive characteristics of an abrasive articles according to the present disclosure, a robotic abrading system can implement force control actuation by corresponding the force between the robot and tool to the force between the bristles of an abrasive article and the workpiece. The present disclosure also discloses methods of abrading a workpiece using force control by such robotic abrading systems without the need for continuous brush wear monitoring, ultimately achieving much higher efficiency.

A robotic abrading system according to various embodiments in the present disclosure can comprise: an abrasive article configured to abrade a workpiece, a tool configured to drive the abrasive article to abrade, a robotic device configured to manipulate the tool with a force control. In various embodiments, the abrasive article can include a circular center member having an outer edge and a radial line, a plurality of bristles extending outward from the outer edge of the circular center member, the bristles comprise a plurality of abrasive particles, at least a portion of the bristles orient with a projection on the plane of the circular center member and the projection is at a slant angle relative to the radial line on the plane of the circular center member. The slant angle is nonorthogonal, preferably in the range of 5 degrees to 60 degrees, and more preferably, in the range of 20 degrees to 45 degrees. In some embodiments, the abrasive article includes a circular center member having an outer edge, a plurality of extruded bristles extending outward from the outer edge of the circular center member, the abrasive article has a first direction of use when the tool rotates in a first direction, and a second direction of use when the tool rotates in a second direction opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is greater than an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

A schematic of a robotic abrading system according to some embodiments of the present disclosure is shown in FIG. 7 and illustrated in FIG. 8. A robotic abrading system 800 includes a robotic device 820, the robotic device 820 may be controlled by one or more controllers 830. Controller 830 may include a motion controller 840, which may receive instructions from one or more application controllers 850. The application controller 850 may optionally receive input, or provide output, to a user interface 860. The robotic device 820 includes a force control unit 824 that can be aligned with an end-effector 826. The end effector 826 can include one or more tools 828.

A robotic device 820 has a base 821, which may be stationary, in some embodiments. In other embodiments, the base 821 can move in any of dimensions, translationally or rotationally about an x-axis, y-axis and/or z-axis. For example, a robotic device 820 may have a base 821 fixed to a rail system configured to travel along a rail. The robotic device 820 can move closer, or further away from a workpiece 880, or move higher or lower with respect to the workpiece 880. A moveable base 821 may make it easier to work on difficult-to-reach area on a workpiece 880. Robotic device 820 has one or more tools 828 that can interact with a workpiece 880. A robotic device 820 can have one or multiple joints 823, each of which can move in at least one direction. In some embodiments where joints 823 are ball joints, they may each also allow for movement in x, y, z-directions. A tool 828 may include, or connect to an abrasive article attachment mechanism 829, or another suitable abrasive tool. A tool 828 can optionally include a spindle configured to receive the circular center member of an abrasive article 870. In some embodiments, the circular center member of the abrasive article 870 can be orthogonal to the spindle. During an abrading operation, the abrasive article attachment mechanism 829 may attach to an abrasive article 870 having bristles, by using adhesive, hook and loop, clip system, vacuum or other suitable attachment system. As mounted to the robotic arm 822, a tool 828 may be positioned within the provided degrees of freedom by the robotic device or any other degrees of freedom with its reference frame. The ability of robotic device to move is important, as it allows access to different positions on a workpiece.

The force control unit 824 is configured to apply a force to the abrasive article 870 and the workpiece 880. For example, with the addition of some advanced force sensing and reactive control loops / algorithms, robot manipulators can apply controlled forces to the workpiece. The forces can be a desired force and/or desired stiffness. The desired force can be predetermined and may comprise a range. The desired stiffness can comprise one or more of an angular stiffness and a lateral stiffness.

The techniques that can be used for force control in a robotic abrading system according to the present disclosure is non-limiting. The robotic abrading system can use force control techniques as described in, for example, PCT Publication Nos. WO 2020/084517 (Mielke et al.); WO 2020/084523 (Hemes et al.); WO 2020/084411 (Hemes et al.). In some embodiments, a robotic abrading system may comprise an actuator positioned between the tool and the workpiece, wherein the actuator is driven to apply a desired force and a desired stiffness to the abrasive article in response to sensed data collected between the tool and the workpiece. A softer redundant actuation can be attached to add compliance, which reduces force-displacement curves and results in systems that can precisely control applied forces over a particular displacement. The actuator can optionally comprise a plurality of internal pressure chambers encapsulated by a deformable material, and wherein the plurality of internal pressure chambers can be arranged in a multitude of different configurations to achieve the desired force and desired stiffness.

In some embodiments, a robot device can be configured to apply a desired force in multiple directions during the same motion. Having an end-effector that allows for multi degree-of-freedom (DOF) control reduces tool switching and orientation change during a task. It also reduces the number of passes needed to complete a multi-dimensional task. The force can be controlled in a feedback loop, where the desired force is input and achieved force is the feedback term.

The robotic abrading system can optionally comprise a pressure supply and a pressure controller coupled with the pressure supply, wherein the pressure controller is configured to measure an implementation force of the robotic device and is configured to control the pneumatic pressure within the pressure supply based upon the implementation force. The pressure supply can be one of internal to or external of the tool. The implementation force can be measured at a flange between the robotic device and the tool.

According to one aspect of the present disclosure, the robotic abrading system 800 can monitor, sense and control one or more components in the system, including the robot arm 822, the end effector 826, the tool 828, the abrasive article and the workpiece.

According to one aspect of the present disclosure, a robotic abrading system may further include at least one sensor or communication-equipped tool stack configured to couple to at least one of the components in the system and the abrasive article. Data gathered by sensor(s) or communication-equipped tool stack from the robot and / or the workpiece can be utilized for automating the process of applications using automated abrasive processing and subsequent polishing. The robotic abrading system optionally further comprises a processor communicating wirelessly with such sensor and/or communication-equipped apparatuses. In various embodiments, the robotic abrading system can include any process-specific tooling required for the objective such as force control sensors and devices, actuators, valves, other controller sensors, etc.

In accordance with some embodiments of the present disclosure, the system includes a learning component and cloud-based process planning and optimization. The disclosed techniques, systems and methods can include novel combinations of robotic (smart) tools, sensing techniques, stochastic process policy that results in desired system behavior based on current part/system state and provided feedback, and an optional learning component capable of optimizing provided process policy, continuously adapting the policy due to customer's upstream process variations, and/or learning the process policy from scratch with little-to-no human intervention.

According to one aspect of the present disclosure, the system may include a computing system that is configured to: receive data from a communication unit regarding a property measured by a sensor or derived indirectly from other data. The data gathered by sensor(s) or communication-equipped tool stack from the robot and/or the workpiece can be utilized for automating the process of applications using automated abrasive processing and subsequent polishing. The system can use the data for control/feedback to guide manipulation of the tool stack by the robot. The computing system can aggregate data from many work sessions. For instance, the computing system can determine (e.g., based on data gathered from the tool stack as previously discussed and other data such as video information, work duration information, abrading tool movement information, temperature information, and/or other data) when an area of a workpiece is complete or other information. Similar information can be used for determining whether the abrasive article is worn out.

In some instances, a computing system can use the data derived from the various sensors and techniques discussed previously in this application for training and improving the operation of robots. In some examples, computing system can train a machine learning system based on the collected data to make determinations regarding whether an area of a workpiece is complete and/or whether the abrasive article is worn out and other determinations. For instance, usage data such as the data gathered with the sensor(s) and other sensors discussed herein can be used as training data for a neural network part of a machine learning routine. Furthermore, the data can be used for manufacturer monitoring of the abrasive article and/or the abrading tool performance for purposes of product improvement.

It is to be recognized that certain acts or events of any of the techniques described herein can be performed in a different sequence, can be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the techniques). Moreover, in certain examples, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors, rather than sequentially.

The techniques of this disclosure can be implemented in a wide variety of devices or apparatuses, including a wireless communication device or wireless handset, a microprocessor, an integrated circuit (IC) or a set of ICs (e.g., a chip set). Various components, modules, or units are described in this disclosure to emphasize functional aspects of devices configured to perform the disclosed techniques, but do not necessarily require realization by different hardware units. Rather, as described above, various units can be combined in a hardware unit or provided by a collection of interoperative hardware units, including one or more processors as described above, in conjunction with suitable software and/or firmware.

The functions, techniques or algorithms described herein may be implemented in software in one example. The software may consist of computer executable instructions stored on computer readable media or computer readable storage device such as one or more non-transitory memories or other type of hardware -based storage devices, either local or networked. Further, such functions correspond to modules, which may be software, hardware, firmware or any combination thereof. Multiple functions may be performed in one or more modules as desired, and the examples described are merely examples. The software may be executed on a digital signal processor, ASIC, microprocessor, or other type of processor operating on a computer system, such as a personal computer, server or other computer system, turning such computer system into a specifically programmed machine.

It should be understood that numerous other arrangements and modifications of the robotic abrading system can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the disclosure.

The present disclosure provides abrasive article including a circular center member having an outer edge, a radial line, and a radial plane; a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member; wherein the bristles comprise a plurality of abrasive particles; wherein at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line; wherein the slant angle is larger than 0 degree.

The abrasive article can include bristles that include an extruded thermoplastic material.

The abrasive article can include bristles that include a polyamide thermoplastic material.

The abrasive article can include bristles that include an extruded thermoplastic elastomer, which can include at least one selected from the group consisting of segmented thermoplastic elastomers, ionomeric thermoplastic elastomers and blends of segmented thermoplastic elastomers and thermoplastic polymers.

The abrasive article can include bristles that include an extruded thermoplastic elastomer, which includes at least one selected from the group consisting of polyesters, polyurethanes, polyamides, and mixtures thereof.

The abrasive article can include a slant angle in the range of 5 degrees to 60 degrees.

The abrasive article can include a slant angle in the range of 20 degrees to 45 degrees.

The abrasive article can include at least a portion of the plurality of bristles having more than one slant angle.

The abrasive article can include at least a portion of the plurality of bristles having a length and the slant angle varies along the length of the bristles. The abrasive article can include at least a portion of the bristles that are coplanar with the radial plane of the center member.

The abrasive article can include at least a portion of the plurality of bristles that are parallel with the radial plane of the center member.

The abrasive article can include at least a portion of the plurality of bristles that are oblique to the radial plane of the center member.

The abrasive article can include the bristles having an aspect ratio of at least 2.

The abrasive article can include the bristles having an aspect ratio of at least 10.

The abrasive article can include abrasive particles that are interspersed throughout each of the bristles.

The abrasive article can include abrasive particles that contain inorganic abrasive particles.

The abrasive article can include abrasive particles that contain organic abrasive particles.

The abrasive article can include abrasive particles that contain formed abrasive particles.

The abrasive article can include abrasive particles that are triangular-prism shaped.

The abrasive article can include abrasive particles wherein at least 50% of the abrasive particles are orientationally aligned.

The abrasive article can include bristles with a first bristle end adjacent to the center member and a second bristle end opposite to the first bristle end, and the bristles have constant cross section from the first bristle end to the second bristle end.

The abrasive article can include an attachment mechanism provided on the center member for attaching the abrasive article to a drive mechanism.

The abrasive article can include a center member further comprises an inner edge, wherein the inner edge defines a hole in the center member.

The abrasive article can include a spindle-receiving mechanism.

The abrasive article can include an inner edge containing threading.

The abrasive article can include an inner edge and an outer edge having concentric circles bounding the center member.

The abrasive article can include a center member having an outer edge; a plurality of extruded bristles extending outward from the outer edge of the center member; wherein the abrasive article has a first direction of use and a second direction of use opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is different from an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

The abrasive article can have a first direction of use and a second direction of use opposite to the first direction of use, and the amount of material removed when the abrasive article is moved in the first direction of use is greater than the amount of material removed when the abrasive article is moved in the second direction.

A method of making an abrasive article, including providing an extrudate comprising a molten polymer; extruding the extrudate through a die to form a plurality of bristles, wherein the bristles comprise a plurality of abrasive particles; attaching the plurality of bristles to a circular center member having an outer edge and a radial line; wherein the bristles extending outward from the outer edge at a slant angle relative to the radial line.

The method of making an abrasive article can include attaching the plurality of bristles at a slant angle is in the range of 5 degrees to 60 degrees.

The method of making an abrasive article can include attaching the plurality of bristles at a slant angle is in the range of 20 degrees to 45 degrees.

The method of making an abrasive article can include adding the abrasive particles to the extrudate before the extrudate passing through the die.

The method of making an abrasive article can include adding the abrasive particles to the extrudate while the extrudate is passing through the die.

The method of making an abrasive article can include using the extrudate including a thermoplastic polymer.

The method of making an abrasive article can include using the extrudate including a polyamide thermoplastic polymer.

The method of making an abrasive article can include using the extrudate including a thermoplastic elastomer, which can contain at least one selected from the group consisting of segmented thermoplastic elastomers, ionomeric thermoplastic elastomers and blends of segmented thermoplastic elastomers and thermoplastic polymers.

The method of making an abrasive article can include using the extrudate including a thermoplastic elastomer, which can contain at least one selected from the group consisting of polyesters, polyurethanes, polyamides, and mixtures thereof.

A robotic abrading system, including an abrasive article configured to abrade a workpiece, wherein the abrasive article comprises a circular center member having an outer edge and a radial line; a plurality of bristles extending outward from the outer edge of the circular center member, wherein the bristles comprise a plurality of abrasive particles; wherein at least a portion of the bristles orient with a projection on the plane of the circular center member; wherein the projection is at a slant angle relative to the radial line on the plane of the circular center member; a tool configured to drive the abrasive article; and a force control, wherein the force control is configured to drive the tool.

The robotic abrading system with an abrasive article having the slant angle is in the range of 5 degrees to 60 degrees.

The robotic abrading system includes a spindle configured to receive the circular center member of the abrasive article.

The robotic abrading system can include a circular center member is orthogonal to the spindle.

A robotic abrading system including an abrasive article configured to abrade a workpiece; a tool configured to drive rotation of the abrasive article against the workpiece such that the abrasive article abrades the workpiece; a robotic device configured to urge the tool toward the workpiece; and wherein the abrasive article comprising: a circular center member having an outer edge; a plurality of extruded bristles extending outward from the outer edge of the circular center member; wherein the abrasive article has a first direction of use, comprising the tool rotating in a first direction, and a second direction of use, comprising the tool rotating in a second direction opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is greater than an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

The robotic abrading system can include an actuator, wherein the actuator applies a force to the abrasive article.

The robotic abrading system can apply a force that is determined in response to sensed data collected between the tool and the workpiece.

The robotic abrading system can include a pressure supply and a pressure controller coupled with the pressure supply.

The robotic abrading system can include a pressure supply that is internal to the tool.

The robotic abrading system can include a pressure supply that is external to the tool.

The robotic abrading system can include a sensor configured to measure operation related data during abrading the workpiece.

The robotic abrading system can include a processor communicating wirelessly with the sensor.

A method of abrading a workpiece using the abrasive article, including contacting the abrasive article with the workpiece with an applied force, wherein the abrasive bristle comprises; a circular center member having a radial line and extruded bristles extending outward from the circular center member at a slant angle in a slant direction relative to the radial line; moving at least one of the abrasive article and the workpiece, wherein the abrasive article has a direction of rotation relative to the workpiece, wherein the direction of rotation is opposite to the slant direction; removing a portion of material of the workpiece.

A method of abrading a workpiece can include using an abrasive article with the slant angle in the range of 5 degrees to 60 degrees.

A method of abrading a workpiece can include applying a force that is constant throughout the life of the abrasive article.

A method of abrading a workpiece can include applying a force that is predetermined.

Objects and advantages of this disclosure are further illustrated by the following non-limiting examples, but the particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this disclosure.

EXAMPLES

Unless otherwise noted, all parts, percentages, ratios, etc. in the Examples and the rest of the specification are by weight. Unless stated otherwise, all reagents were obtained or are available from chemical vendors such as Sigma-Aldrich Company, St. Louis, Missouri, or may be synthesized by known methods. Unit Abbreviations used in the Examples: cm = centimeter; mm = millimeter; °C = degree Celsius, lbf = pound force.

Materials used in the Examples:

Table 1

ABBREVIATION	DESCRIPTION
SAP1	Formed abrasive particles prepared according to the disclosure of U.S. Pat. No. 8,142,531 (Adefris et al.). The formed abrasive particles were prepared by molding alumina sol gel in equilateral triangle-shaped polypropylene mold cavities of 0.25-millimeter depth and 1.001 millimeters on each side. The draft angle between the sidewall and bottom of the mold was 98 degrees. The particles were then treated as described in the disclosure of U.S. Pat. No. 5,213,591 (Celikkaya et al.). The formed abrasive particles made as described above are used, for example, in 3M 987C CUBITRON II 80+ grade abrasive discs available from 3M Company, St. Paul, Minnesota, USA.
SAP2	Formed abrasive particles prepared according to the disclosure of U.S. Pat. No. 8,142,531 (Adefris et al.). The formed abrasive particles were prepared by molding alumina sol gel in equilateral triangle-shaped polypropylene mold cavities of 0.25-millimeter depth and 1.001 millimeters on each side. The draft angle between the sidewall and bottom of the mold was 98 degrees. The particles were then treated as described in the disclosure of U.S. Pat. No. 5,213,591 (Celikkaya et al.). The formed abrasive particles made as described above are used, for example, in 3M CUBITRON II Hookit Clean Sanding Abrasive Discs 737U 120+ grade abrasive discs available from 3M Company, St. Paul, Minnesota, USA.
NYLON 6,12	A polyamide thermoplastic polymer, available from E.I. Dupont de Nemours and Company, Inc., Wilmington, Delaware, USA.

Example 1

The extruded bristles containing 70% NYLON 6,12 and 30% SAP1 by weight percentages was obtained as ABRAFIL 043-080-30CR612C Lot 64833 from Perlon-Hahl Inc., Lexington, South Carolina. The bristles measured 1.1 mm (0.043-inch) in diameter. A circular molded center member with a center hole of 50.8 mm (2 inches) in diameter was used. The bristles were attached to the center member prior to addition and solidification of urethane resin, which was used to fabricate the center member to hold the bristles in position. The bristles were positioned with a slant angle of 30 degrees relatively to the radial line R of the center member and were crimped. The resulting brush (abrasive article) was 15.24 cm (6-inch) in diameter and 6.35 mm (0.25-inch) wide.

Comparative Example A

Comparative Example A was prepared generally by the method described in Example 1 with the exception that the bristles were positioned along the radial line R of the center member (no slant angle).

Force/Brush Interference Testing

The abrasive articles from Example 1 and Comparative Example A were run for force/brush interference testing. The abrasive articles from Example 1 and Comparative Example A were both mounted together on the arbor to make a 0.5-inch (12.7 mm) wide brush face. For Example 1, the abrasive article was driven to rotate in the direction that is opposite to the slant direction of the bristles (the direction in which the bristles were slanted relative to the radial line). The rotation speed was at 1750 RPM. The force exerted by a rotating brush on a rotating spindle as it was pushed into the brush face was recorded. A plot of Force in lbf versus the Interference Depth in mm is shown in FIG. 11 for three consecutive tests.

It is found that Comparative Example A displayed a rapid increase a rapid rise in force to a peak of 6 lbf (26.7 Newtons) at interference depth of 3 mm which then levels off. In contrast, Example 1 displayed a consistent behavior with a relatively linear increase beginning at interference depth of 1.0 mm to the end at 7.6 mm with a slope of 0.7 lbf/mm (3.1 Newtons per mm).

Example 2

The extruded bristles containing 70% NYLON 6,12 and 30% SAP2 by weight percentages was made with the bristles measured from 0.64 mm (0.025-inch) to 0.76 mm (0.030-inch) in diameter. A circular molded center member with a center hole of 50.8 mm (2 inches) in diameter was used. The bristles were attached to the center member prior to addition and solidification of urethane resin, which was used to fabricate the center member to hold the bristles in position. The bristles were positioned with a slant angle of 30 degrees relatively to the radial line R of the center member and were crimped. The resulting brush (abrasive article) was 15.24 cm (6-inch) in diameter and 6.35 mm (0.25-inch) wide. A top view image of the abrasive article made from Example 2 is shown in FIG. 10.

Comparative Example B

Comparative Example B was prepared generally by the method described in Example 1 with the exception that the bristles were positioned along the radial line R of the center member (no slant angle).

Surface Finish Test

The abrasive articles from Example 2 and Comparative Example B were tested for surface finish performance. For each Example, two abrasive articles were mounted together to make a 0.5-inch (1.3 cm) wide face brush on the arbor of a servo motor and were driven to rotate at 1750 RPM against a plate of cartridge brass with the dimension of 2-inch (5.1 cm) × 11-inch (27.9 cm) × 0.060-inch (1.5 mm). The plate was moved with the rotation of the abrasive article (downfeed) along a 6-inch (15.2 cm) length with a traverse speed of 3 inch per second (7.6 cm per second); the surface was abraded for twenty strokes. In the first test, the applied force was maintained at 5 lbf (22.2 Newtons). In the second test, the force was applied to achieve a 3.0 mm insertion depth per the Force/Brush Interference test results. For Example 2, the corresponding applied force was 0.86 lbf (3.8 Newtons). For Comparative Example B, the corresponding applied force was 1.74 lbf (7.7 Newtons). The surface finish of the abraded and unabraded portion of the plates was measured with a Hommel T8000 Profilometer using a 2-micron diamond stylus with Lc set at 0.03 inch (0.76 mm) and Lt set at 0.15 inch (3.8 mm). Five traces were taken at 1-inch (2.54-cm) increments along the 6-inch (15.24-cm) abraded length of the plate, starting 1.5 inches (3.8 cm) from the beginning of the abraded surface. In the second test, two measurements were made for each sample: one measured for the surface abraded by the outer bristles of the brush, while the other one measured for the surface abraded by the inner bristles of the brush. "Outer" and "Inner" in the results designated these values, respectively. The results for Ra are shown in Table 2.

Table 2

Samples	5 lbf	Interference Depth at 3 mm	
		0.86 lbf	1.74 lbf
Example 2	56.1027	44.7196 (Inner) 57.8624 (Outer)	Not Applicable
Comparative Example B	38.6230	Not Applicable	52.4150 (Inner) 77.7576 (Outer)
Cartridge Brass Unabraded	12.1824	Not Applicable	Not Applicable

It is found that when the forces were adjusted to obtain same interference depths, the surface finish results from the abrasive articles from Example 2 and Comparative Example B are comparable.

<u>Cut Performance Test</u>

The abrasive articles made according to Example 1 and Comparative Example A were tested for cut performance evaluation in the following manner. For each Example, two abrasive articles were mounted together to make a 0.5-inch (1.3 cm) wide face brush. The brush was rotated at a speed of 1750 RPM and moved into a position to achieve an interference depth of 0.100-inch (2.54 mm) with the edge of a 304 Stainless Steel (304SS) strip with a 0.062-inch (1.6 mm) thickness. The infeed speed of the strip was 8 inches (20.3 cm) per second. A burr was ground into the strip edge with an A24 vitrified bonded cup wheel until the burr measured ~ 0.20 to 0.25 mm above the surface of the strip. The edge was brushed for 5 minutes and the height of the burr was measured using a Keyence LJ-V7020B Laser Line Sensor attached to a Keyence XG-X2902 computer. Data was generated using a program written in Keyence XG-X Vision Editor. Eight burr height measurements are taken at 15-inch (38.1 cm) intervals in one pass over a 120-inch (304.8 cm) length of the 304SS strip. The data is presented in FIG. 12 as the mean of the eight readings to represent mean burr height after passes. The data shows the cut achieved by for Example 1 and Comparative Example A are relatively similar.

The torque requirements on the motor were also recorded during the cut performance test performed by Example 1 and Comparative Example A. The torque requirement on the motor for Comparative Example A registered at 1.75 foot-pound force (ft·lbf), while the torque requirement on the motor for Comparative Example A registered at only 1.0 ft·lbf. It is unexpected to find a significant reduction in motor capacity required to achieve the deburring conducted by the abrasive article according to the present disclosure.

Example 3

A robotic abrading system was made by attaching an abrasive article according to Example 1 to a robotic device. A part of the robotic abrading system made is shown as FIG. 13. The robotic abrading system 1300 was made by attaching the abrasive article 1301 (made in Example 1) to a robotic device 1320 (available from Kuka, Augsburg, Germany) to provide the robotic abrading system 1300.

All cited references, patents, and patent applications in this application are incorporated by reference in a consistent manner. In the event of inconsistencies or contradictions between portions of the incorporated references and this application, the information in this application shall control. The preceding description, given in order to enable one of ordinary skill in the art to practice the claimed disclosure, is not to be construed as limiting the scope of the disclosure, which is defined by the claims and all equivalents thereto.

What is claimed is:

1. An abrasive article comprising:

a circular center member having an outer edge, a radial line, and a radial plane;

a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member;

wherein the bristles comprise a plurality of abrasive particles;

wherein at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line;

wherein the slant angle is larger than 0 degree.

2. The abrasive article of claim 1, wherein the bristles comprise an extruded thermoplastic polymer.

3. The abrasive article of claim 1 or claim 2, wherein the bristles comprise polyamide thermoplastic polymer.

4. The abrasive article of any one of claims 1-3, wherein the bristles comprise an extruded thermoplastic elastomer.

5. The abrasive article of claim 4, wherein the thermoplastic elastomer comprises at least one selected from the group consisting of polyesters, polyurethanes, polyamides, and mixtures thereof.

6. The abrasive article of any one of claims 1-5, wherein the slant angle is in the range of 5 degrees to 60 degrees.

7. The abrasive article of any one of claims 1-6, wherein the slant angle is in the range of 20 degrees to 45 degrees.

8. The abrasive article of any one of claims 1-7, wherein at least a portion of the plurality of bristles have more than one slant angle.

9. The abrasive article of any one of claims 1-8, wherein at least a portion of the plurality of bristles have a length and the slant angle varies along the length of the bristles.

10. The abrasive article of any one of claims 1-9, wherein at least a portion of the plurality of bristles are coplanar with the radial plane of the center member.

11. The abrasive article of any one of claims 1-10, wherein at least a portion of the plurality of bristles are parallel with the radial plane of the center member.

12. The abrasive article of any one of claims 1-11, wherein at least a portion of the plurality of bristles are at an oblique angle with respect to the radial plane of the center member.

13. The abrasive article of any one of claims 1-12, wherein the bristles have an aspect ratio of at least 2.

14. The abrasive article of any one of claims 1-13, wherein the bristles have an aspect ratio of at least 10.

15. The abrasive article of any one of claims 1-14, wherein the abrasive particles are interspersed throughout each of the bristles.

16. The abrasive article of any one of claims 1-15, wherein the abrasive particles comprise inorganic abrasive particles.

17. The abrasive article of any one of claims 1-16, wherein the abrasive particles comprise organic abrasive particles.

18. The abrasive article of any one of claims 1-17, wherein the abrasive particles comprise formed abrasive particles.

19. The abrasive article of any one of claims 1-18, wherein the abrasive particles are triangular-prism shaped.

20. The abrasive article of claims 1-19, wherein at least 50% of the abrasive particles are orientationally aligned.

21. The abrasive article of any one of claims 1-20, wherein the bristles each comprise a first bristle end adjacent to the center member and a second bristle end opposite to the first bristle end, and wherein the bristles have constant cross section from the first bristle end to the second bristle end.

22. The abrasive article of any one of claims 1-21, further comprising an attachment mechanism provided on the center member for attaching the abrasive article to a drive mechanism.

23. The abrasive article of any one of claims 1-22, wherein the center member further comprises an inner edge, wherein the inner edge defines a hole in the center member.

24. The abrasive article of claim 23, wherein inner edge comprises a spindle-receiving mechanism.

25. The abrasive article of claim 23 or claim 24, wherein inner edge comprises threading.

26. The abrasive article of any one of claims 23-25, wherein the inner edge and the outer edge comprise concentric circles bounding the center member.

27. An abrasive article comprising:

a center member having an outer edge;

a plurality of extruded bristles extending outward from the outer edge of the center member;

wherein the abrasive article has a first direction of use and a second direction of use opposite to the first direction of use;

wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is different from an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

28. The abrasive article of claim 27, wherein the amount of material removed when the abrasive article is moved in the first direction of use is greater than the amount of material removed when the abrasive article is moved in the second direction.

29. A method of making an abrasive article, comprising:

providing an extrudate comprising a molten polymer;

extruding the extrudate through a die to form a plurality of bristles, wherein the bristles comprise a plurality of abrasive particles;

attaching the plurality of bristles to a circular center member having an outer edge and a radial line; wherein the bristles extending outward from the outer edge at a slant angle relative to the corresponding radial line.

30. The method of claim 29, wherein the slant angle is in the range of 5 degrees to 60 degrees.

31. The method of claim 29 or claim 30, wherein the slant angle is in the range of 20 degrees to 45 degrees.

32. The method of any one of claims 29-31, wherein the abrasive particles are applied to the extrudate before the extrudate passing through the die.

33. The method of any one of claims 29-31, wherein the abrasive particles are applied while the extrudate is passing through the die.

34. The method of any one of claims 29-33, wherein the extrudate comprises a thermoplastic polymer.

35. The method of any one of claims 29-34, wherein the extrudate comprises a polyamide thermoplastic polymer.

36. The method of claim 35, wherein the extrudate comprises a thermoplastic elastomer.

37. A robotic abrading system, comprising:

an abrasive article configured to abrade a workpiece, wherein the abrasive article comprises a circular center member having an outer edge and a radial line; a plurality of bristles extending outward from the outer edge of the circular center member and having a projection on the radial plane of the center member, wherein the bristles comprise a plurality of abrasive particles; wherein at least a portion of the bristles orient with the projection at a slant angle relative to the corresponding radial line;

a tool configured to drive the abrasive article; and

a force control, wherein the force control is configured to drive the tool.

38. A robotic abrading system of claim 37, wherein the slant angle is in the range of 5 degrees to 60 degrees.

39. A robotic abrading system of claim 37 or claim 38, wherein the robotic abrading system comprises a spindle configured to receive the circular center member of the abrasive article.

40. A robotic abrading system of claim 39, wherein the circular center member is orthogonal to the spindle.

41. A robotic abrading system, comprising:

an abrasive article configured to abrade a workpiece;

a tool configured to drive rotation of the abrasive article against the workpiece such that the abrasive article abrades the workpiece;

a robotic device configured to urge the tool toward the workpiece; and

wherein the abrasive article comprising: a circular center member having an outer edge; a plurality of extruded bristles extending outward from the outer edge of the circular center member;

wherein the abrasive article has a first direction of use, comprising the tool rotating in a first direction, and a second direction of use, comprising the tool rotating in a second direction opposite to the first direction of use; wherein under the same testing conditions, an amount of material removed from a workpiece when the abrasive article is moved in the first direction of use is greater than an amount of material removed of a workpiece when the abrasive article is moved in the second direction.

42. The robotic abrading system of any one of claims 37-41, further comprising an actuator, wherein the actuator applies a force to the abrasive article.

43. The robotic abrading system of claim 42, wherein the force is determined in response to sensed data collected between the tool and the workpiece.

44. The robotic abrading system of any one of claims 37-43, further comprising a pressure supply and a pressure controller coupled with the pressure supply.

45. The robotic abrading system of claim 44, wherein the pressure supply is internal to the tool.

46. The robotic abrading system of claim 44, wherein the pressure supply is external to the tool.

47. The robotic abrading system of any one of claims 37-46, further comprising a sensor configured to measure operation related data during abrading the workpiece.

48. The robotic abrading system of any one of claims 37-47, further comprising a processor communicating wirelessly with the sensor.

49. A method of abrading a workpiece using the abrasive article, the method comprising:

contacting the abrasive article with the workpiece with an applied force, wherein the abrasive bristle comprises; a circular center member having a radial line and extruded bristles extending outward from the circular center member at a slant angle in a slant direction relative to the corresponding radial line;

moving at least one of the abrasive article and the workpiece, wherein the abrasive article has a direction of rotation relative to the workpiece, wherein the direction of rotation is opposite to the slant direction;

removing a portion of material of the workpiece.

50. The method of claim 49, wherein the slant angle is in the range of 5 degrees to 60 degrees.

51. The method of claim 49 or claim 50, wherein the applied force is constant throughout the life of the abrasive article.

52. The method of any one of claims 49-51, wherein the applied force is predetermined.

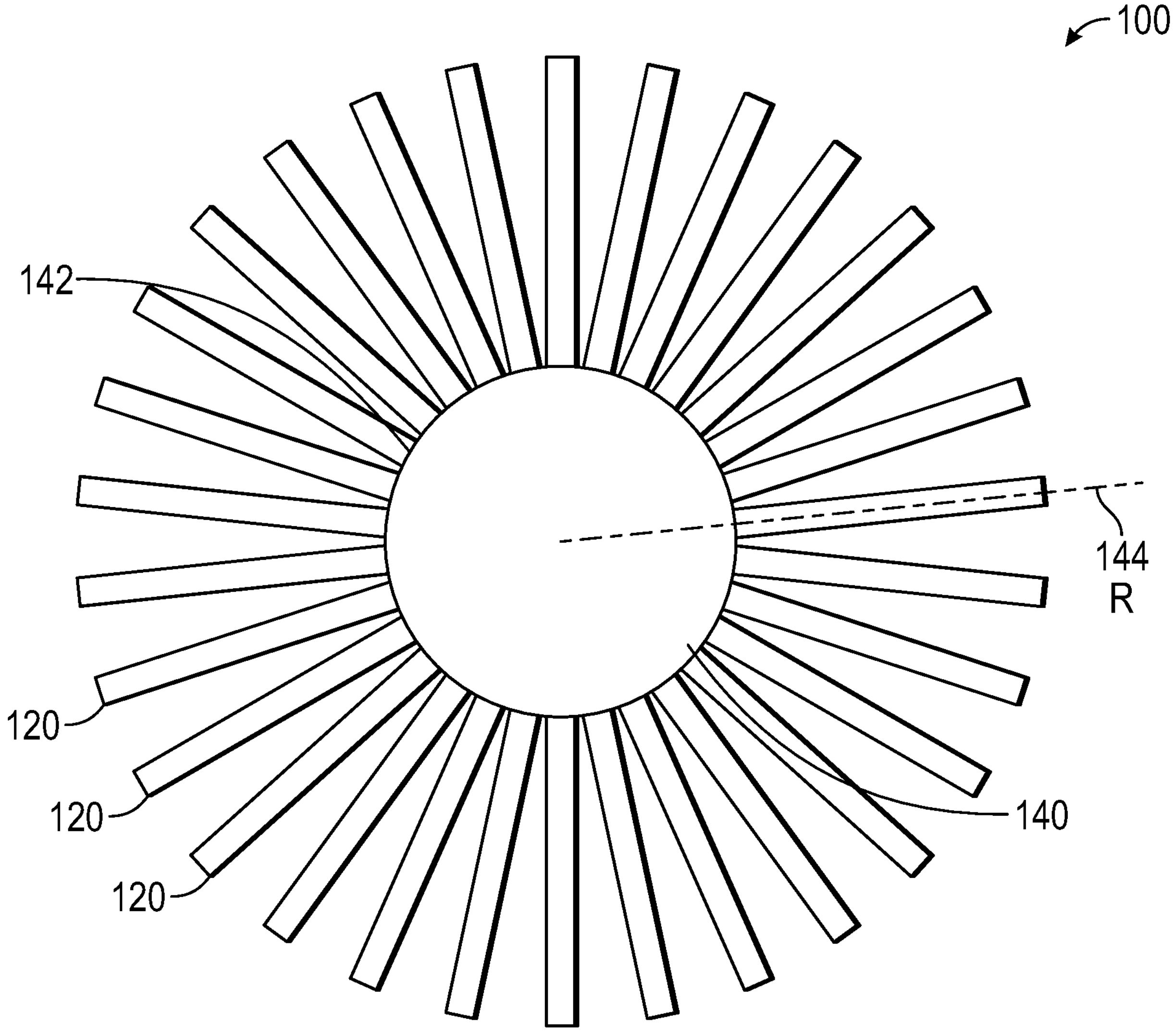


FIG. 1
(Prior Art)

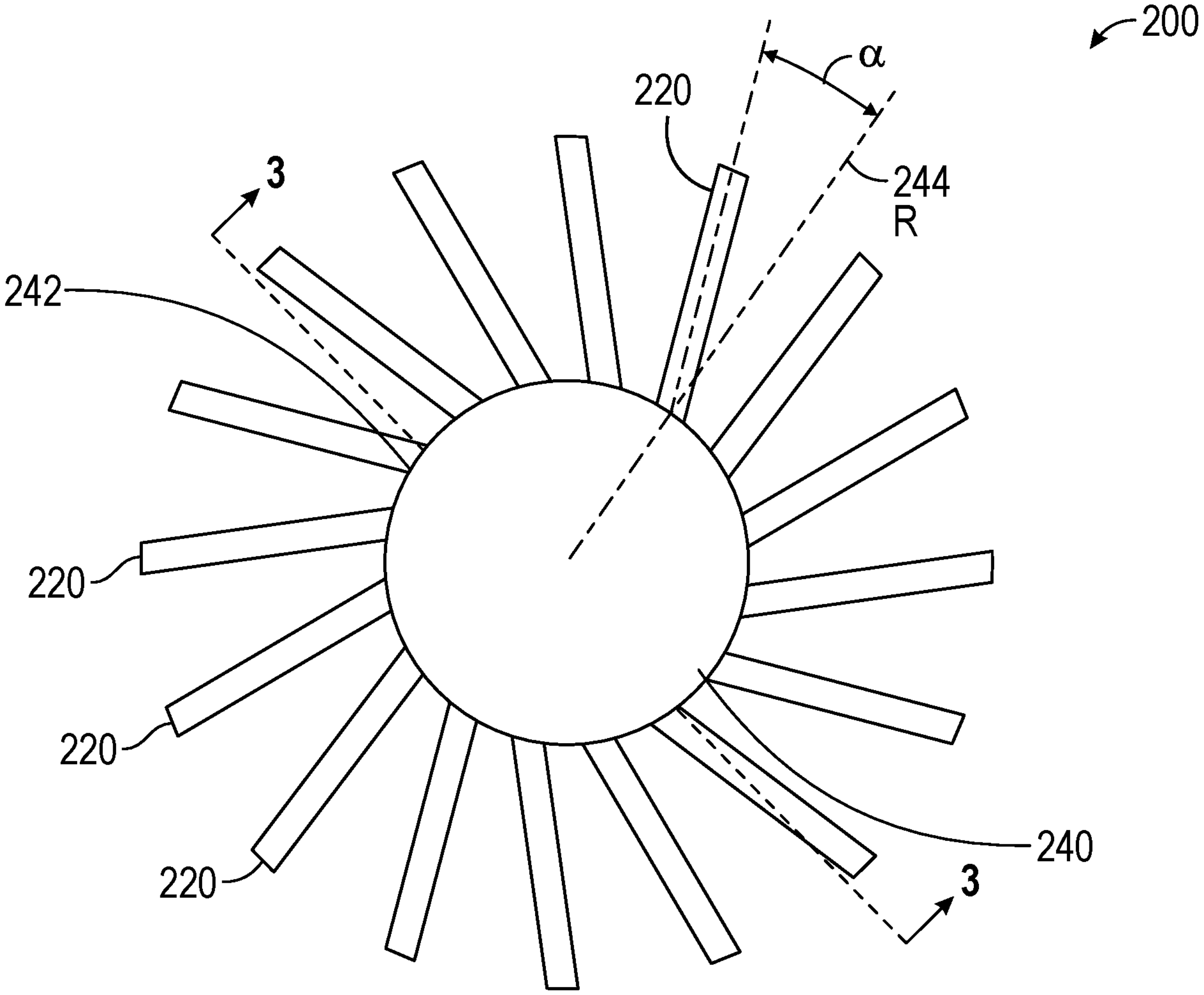


FIG. 2

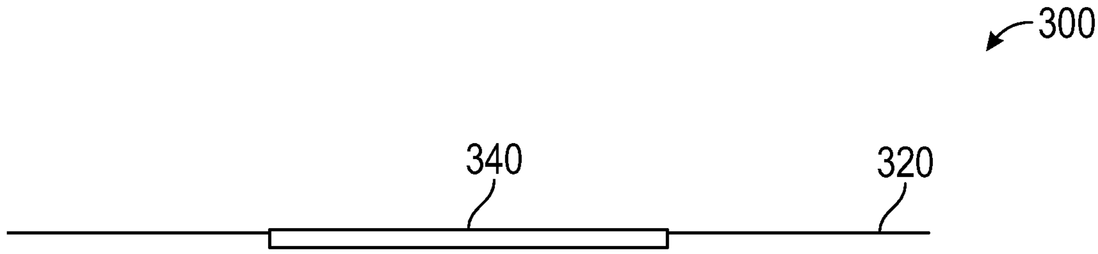


FIG. 3A

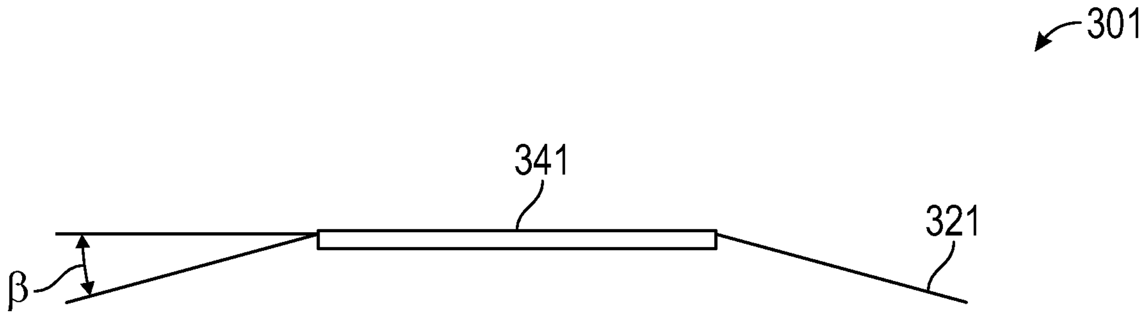


FIG. 3B

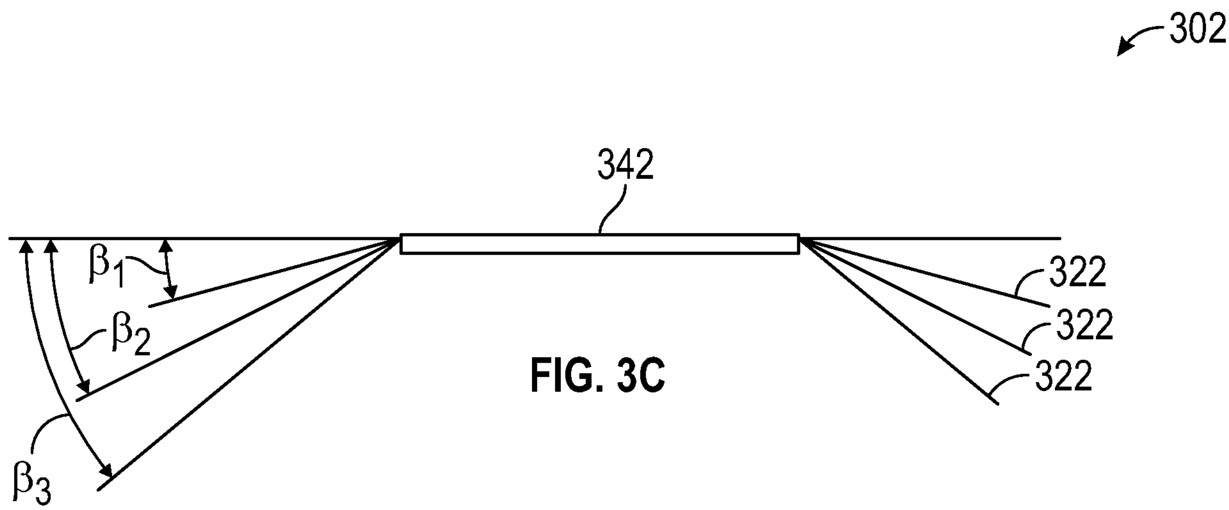


FIG. 3C

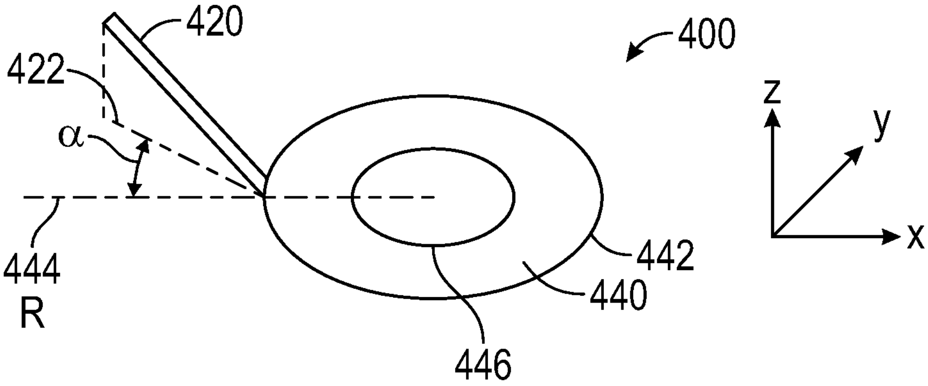


FIG. 4

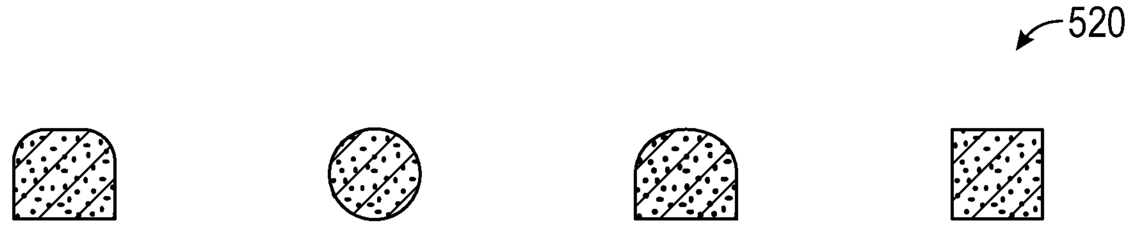


FIG. 5A FIG. 5B FIG. 5C FIG. 5D

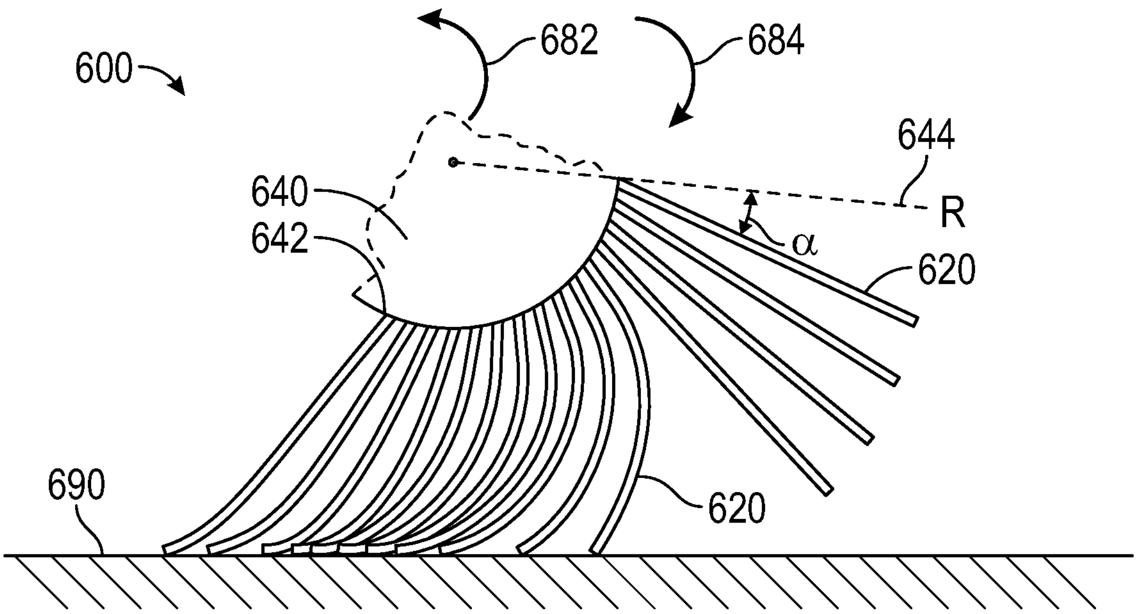
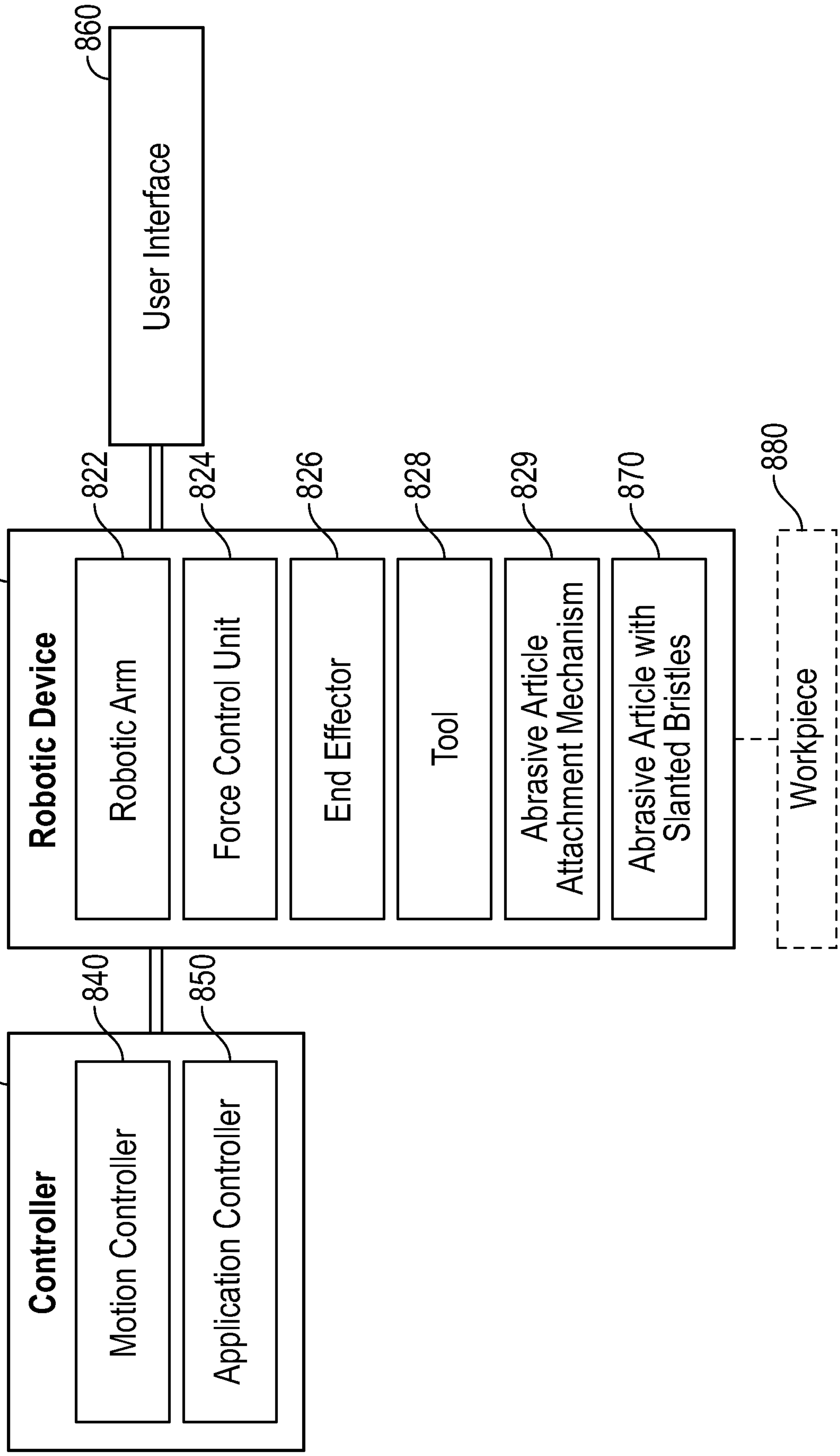


FIG. 6



860
User Interface
820
Robotic Device
822
Robotic Arm
824
Force Control Unit
826
End Effector
828
Tool
829
Abrasive Article Attachment Mechanism
870
Abrasive Article with Slanted Bristles
880
Workpiece
830
Controller
840
Motion Controller
850
Application Controller

FIG. 7

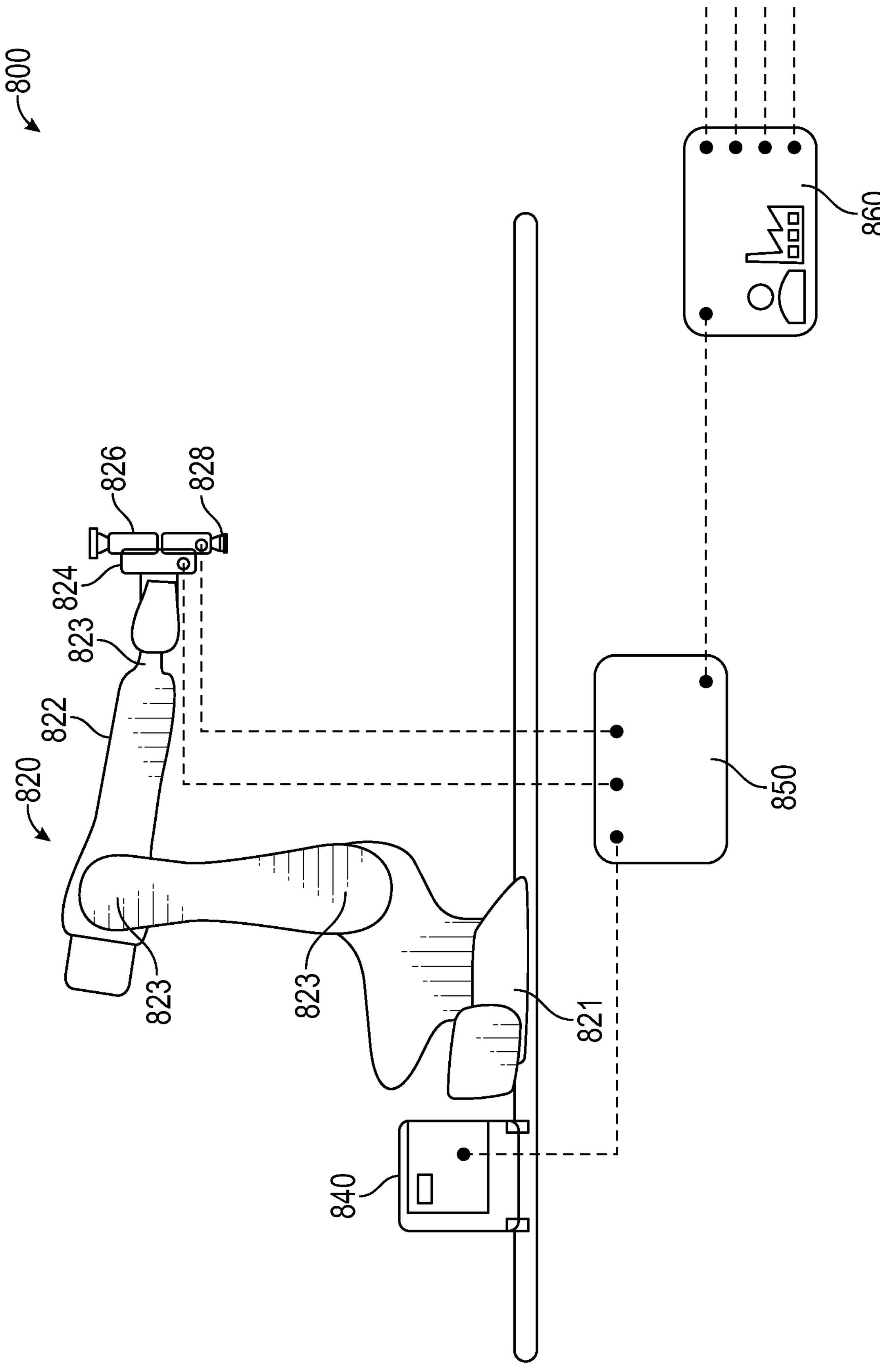


FIG. 8

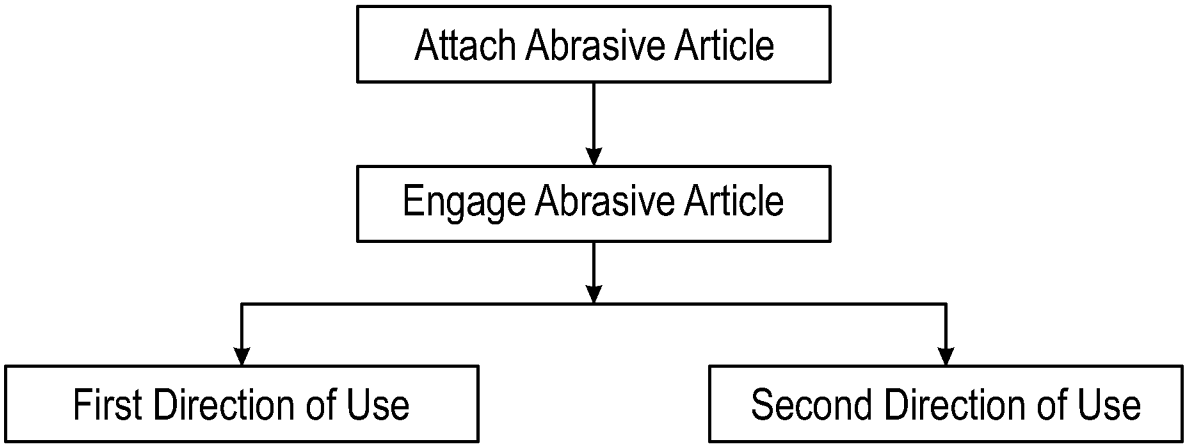

Attach Abrasive Article
Engage Abrasive Article
First Direction of Use
Second Direction of Use

FIG. 9

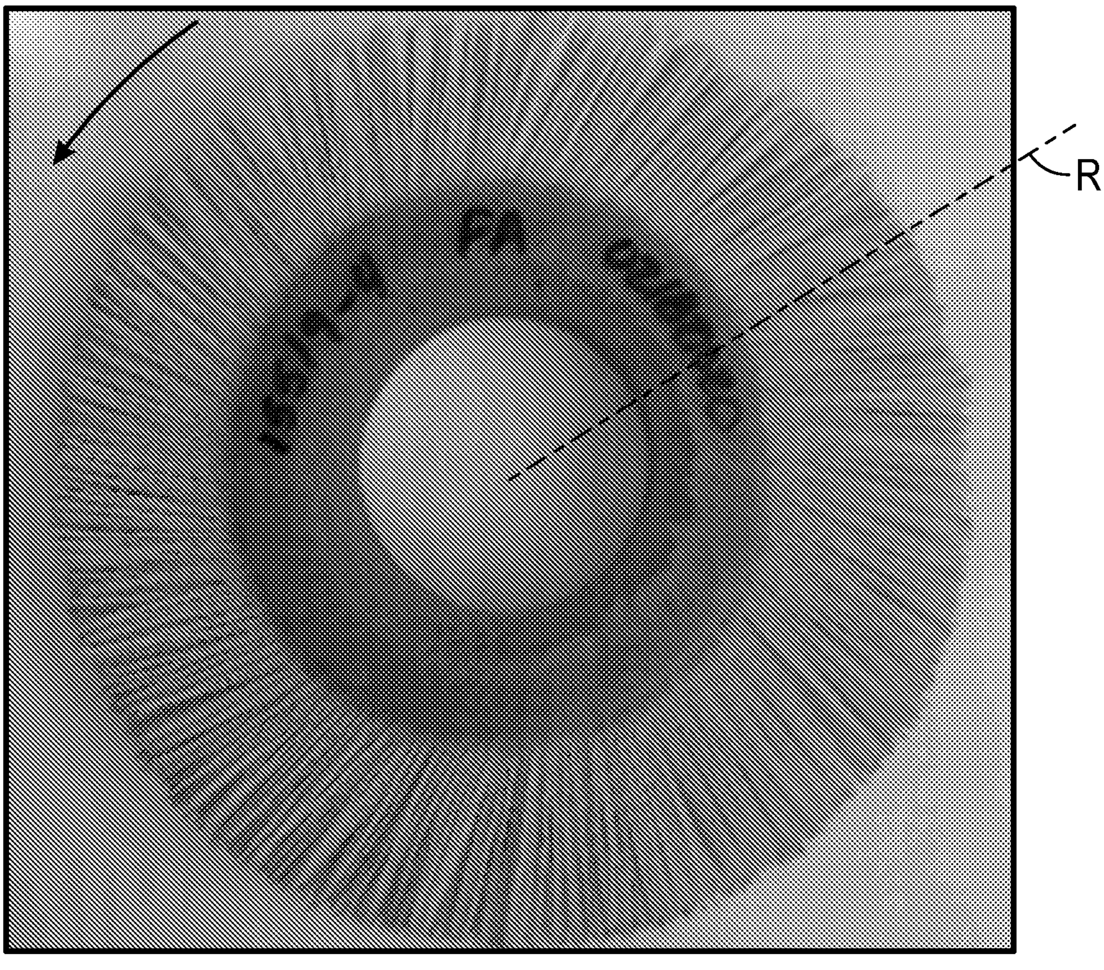

R

FIG. 10

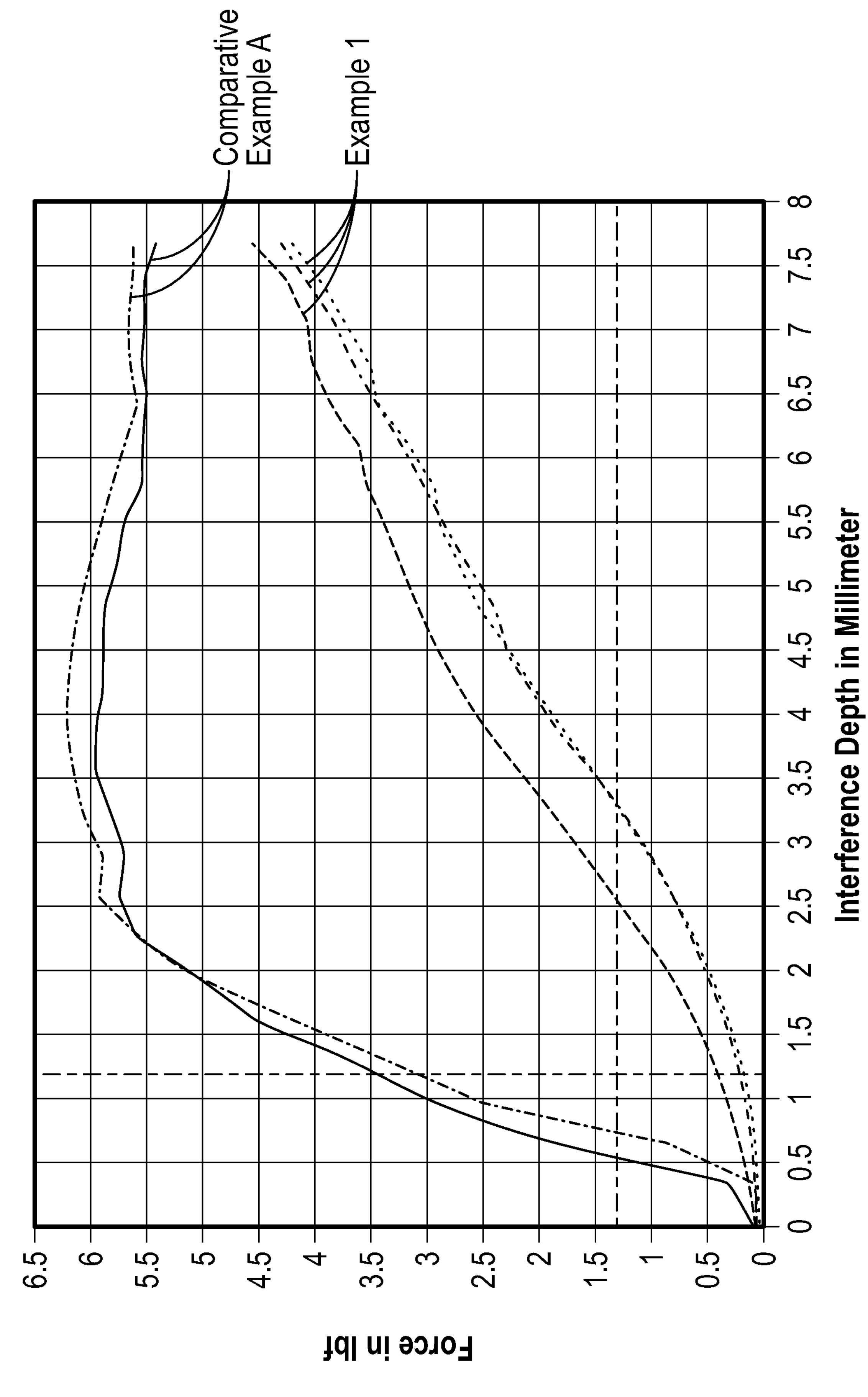

Comparative
Example A
Example 1
Force in lbf
Interference Depth in Millimeter
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8

FIG. 11

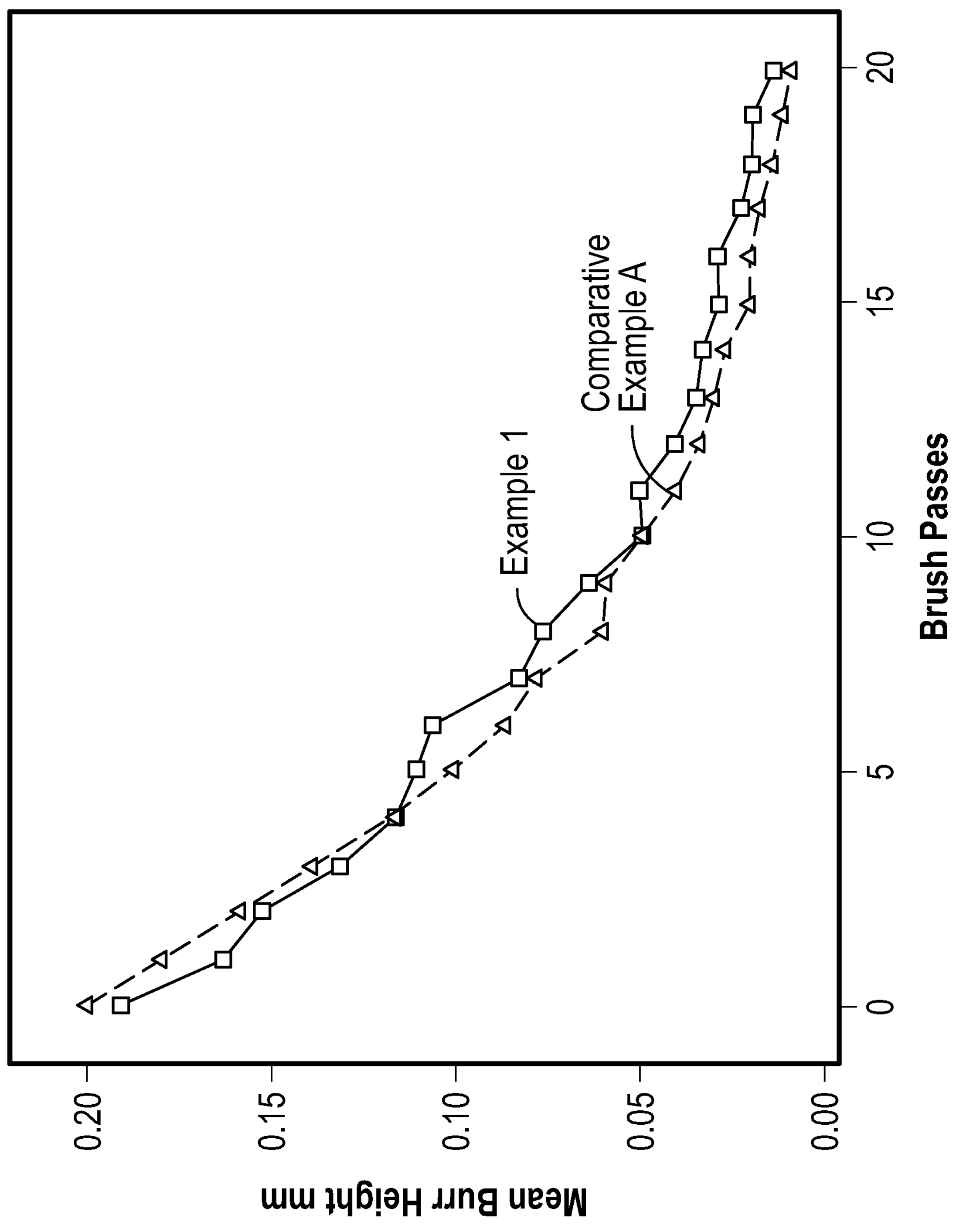

Mean Burr Height mm
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Brush Passes
Example 1
Comparative Example A

FIG. 12

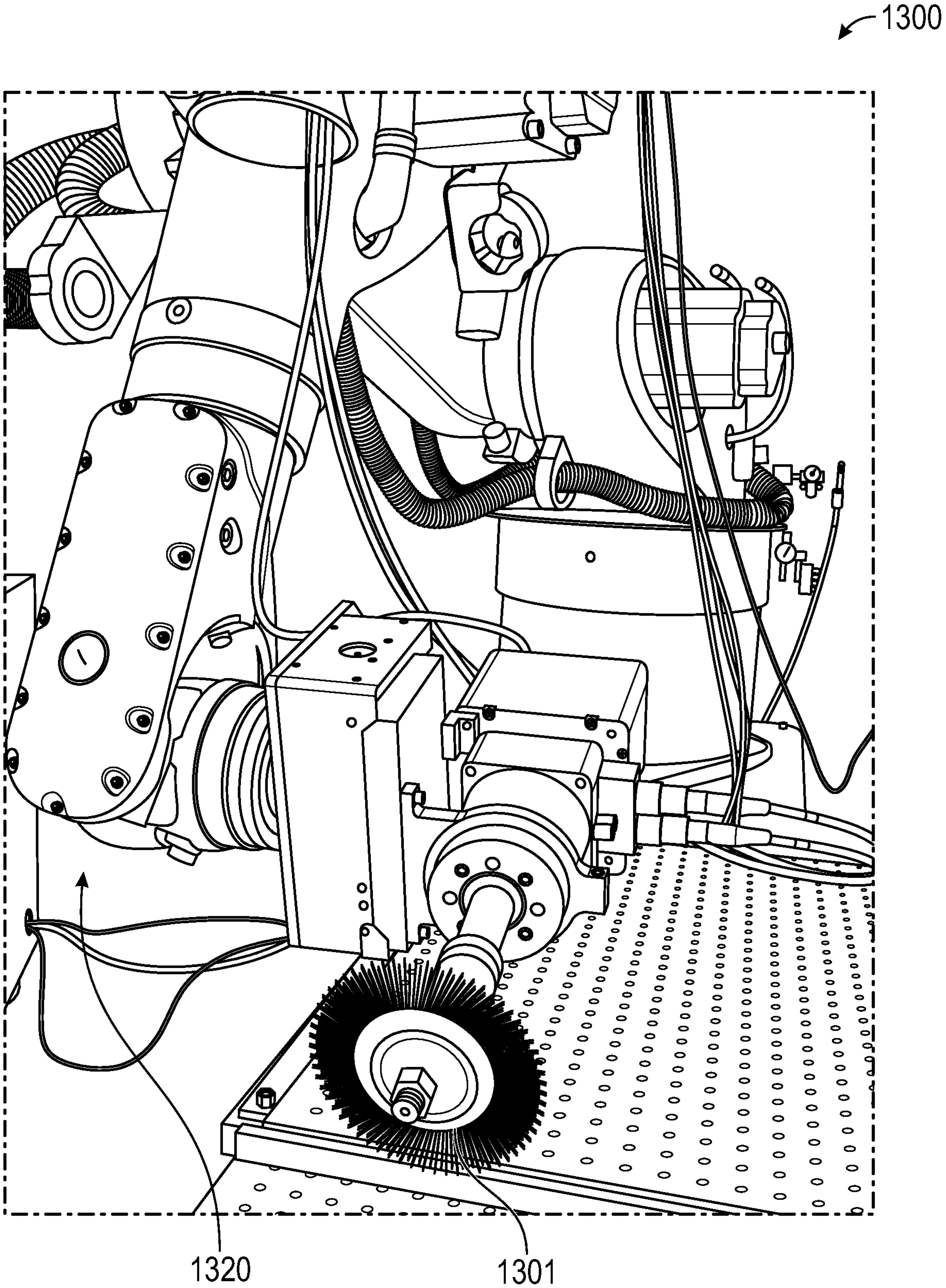


FIG. 13

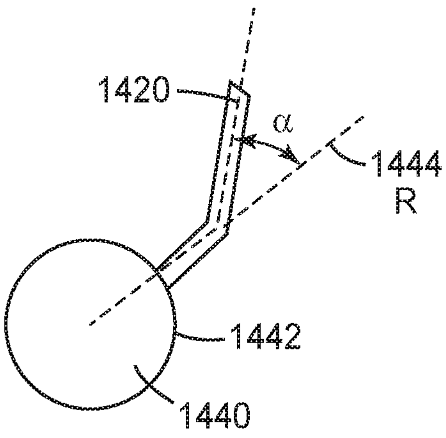


FIG. 14A

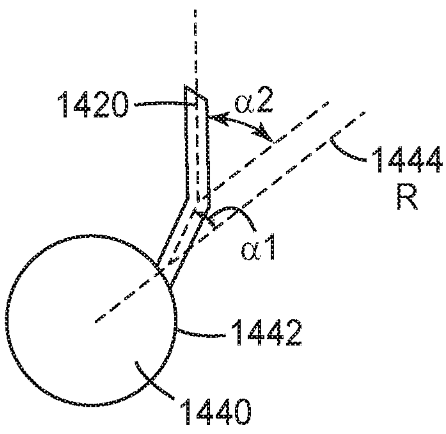


FIG. 14B

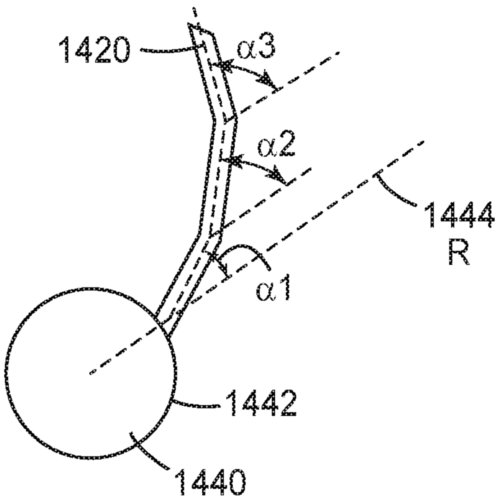


FIG. 14C

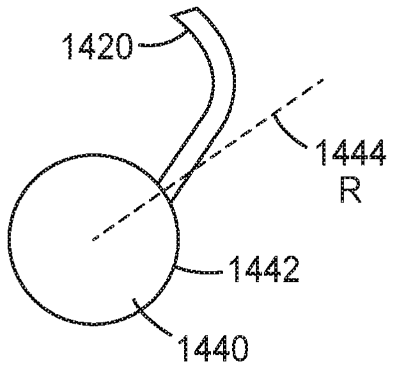


FIG. 14D

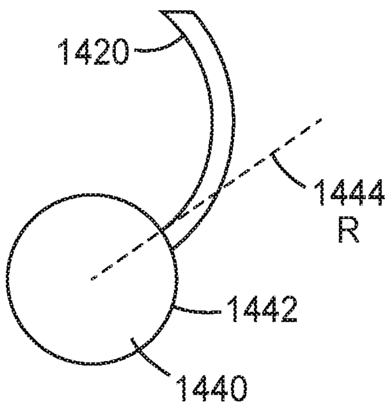


FIG. 14E

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2022/061601

A. CLASSIFICATION OF SUBJECT MATTER
INV. B24D13/10 B24D13/14 B24B27/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B24D B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/132572 A1 (LAGESON KENT E [US] ET AL) 19 September 2002 (2002-09-19)	1-7, 10-20, 22-36, 49,50
Y	paragraphs [0002], [0009], [0011], [0031], [0032], [0033], [0040] - [0041], [0066]; figure 1	8,9,21, 37-40, 42-48, 51,52

Y	US 2020/238463 A1 (NADERER RONALD [AT]) 30 July 2020 (2020-07-30)	21, 37-40, 42-46
	paragraphs [0012], [0019] - [0023]; figure 3	

Y	US 2017/014968 A1 (PALMIERI BARTOLOMEO [US] ET AL) 19 January 2017 (2017-01-19) paragraphs [0025] - [0026]; figure 2	47,48, 51,52

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 March 2023	22/03/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bonetti, Serena

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 101 160 847 B1 (MA SAN CO LTD [KR]) 29 June 2012 (2012-06-29) figure 3 -----	8
Y	RU 2 570 860 C2 (MONTI VERKTSOJGE GMBKH [DE]) 10 December 2015 (2015-12-10) figure 1 -----	9
X	DK 2020 70586 A1 (ELTRONIC WIND SOLUTIONS AS [DK]) 29 September 2021 (2021-09-29)	41,47
Y	p. 2, l. 1-5 p. 2, l. 25-30 p. 5, l. 4-9 p. 5, l. 15-17 p. 7, l. 3-15; figures 6-8 -----	42-46,48

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2022/061601

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [X] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-40, 49-52(completely); 42-48(partially)

   An abrasive article according to claim 1 and a method to produce such abrasive article according to claim 29, characterized by the special technical feature that the bristles comprise a plurality of abrasive particles. Problem solved: improve the abrasiveness of the abrasive article.

   ---

2. claims: 41(completely); 42-48(partially)

   A robotic abrasive system according to claim 41, characterised by the special technical feature that the abrasive tool has a first direction of use and a second direction of use, opposite the first direction of use. Problem solved: increase the flexibility of use of the robotic abrasive system.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2022/061601

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2002132572	A1	19-09-2002	US	6422932	B1	23-07-2002
			US	2002132572	A1	19-09-2002
US 2020238463	A1	30-07-2020	CN	111225765	A	02-06-2020
			DE	102017124326	A1	18-04-2019
			EP	3697567	A1	26-08-2020
			JP	2020537597	A	24-12-2020
			KR	20200069309	A	16-06-2020
			US	2020238463	A1	30-07-2020
			WO	2019077007	A1	25-04-2019
US 2017014968	A1	19-01-2017	EP	3056312	A1	17-08-2016
			US	2017014968	A1	19-01-2017
KR 101160847	B1	29-06-2012	NONE			
RU 2570860	C2	10-12-2015	BR	112013006849	A2	14-06-2016
			CA	2812466	A1	29-03-2012
			CN	103249524	A	14-08-2013
			DE	102010046398	A1	29-03-2012
			EP	2618965	A1	31-07-2013
			JP	5758005	B2	05-08-2015
			JP	2013538699	A	17-10-2013
			KR	20130126599	A	20-11-2013
			RU	2013118719	A	27-10-2014
			US	2014299153	A1	09-10-2014
			WO	2012038537	A1	29-03-2012
DK 202070586	A1	29-09-2021	DK	202070586	A1	29-09-2021
			WO	2022053119	A1	17-03-2022