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(71) Applicants: SAINT-GOBAIN ABRASIVES, INC.

[US/US]; One New Bond Street, Worcester, Massachusetts 01615 (US). SAINT-GOBAIN ABRASIFS [FR/FR]; Rue de l'Ambassadeur, 78700 Conflans-Sainte-Honorine (FR).

(72) Inventors: HARALUR, Gurulingamurthy M.; A3E Reg-

gal Palm Gardens, Chennai 600042 (IN). KOMATH, Shyam Prasad; Door 9, Avatar Apartments, Balakrishnan Road, 2nd Seaward Road, Thiruvannmiyur, Chennai 600041 (IN). SANKARANARAYANAN, Jagadis; Door #6, First Floor, Railway colony 5th Layout, Mahalakshmi Nagar, Chennai 600088 (IN). RAMESH, Nivarthi; 4/360, Jeyendra Colony, Kandanchavady, Chennai 600096 (IN).

(74) Agent: GUO, Lei et al.; Abel Law Group, LLP, 8911 N.

Capital of Texas Hwy, Bldg 4, Suite 4200, Austin, Texas 78759 (US).

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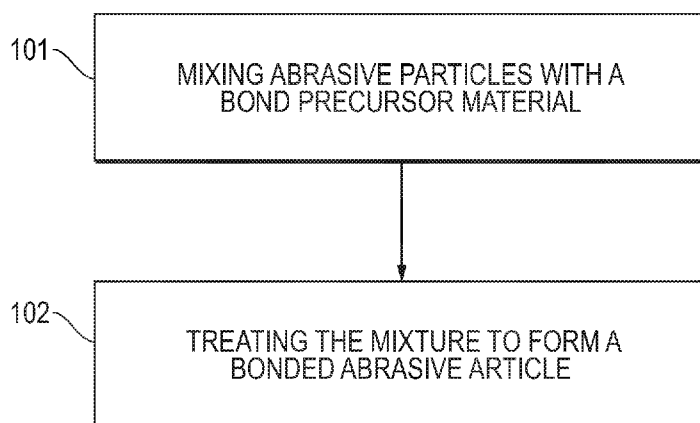
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(54) Title: ABRASIVE ARTICLES AND METHODS FOR FORMING SAME

FIG. 1



(57) Abstract: An abrasive article can include a body including a bond material and abrasive particles contained within the bond material. The bond material can include a siloxane functional group covalently bonded to a plurality of benzene rings. In an embodiment, the bond material can include at least one siloxane functional group covalently bonded to a phenoxy. In a particular embodiment, the bond material can include polydimethylsiloxane covalently bonded to a phenoxy. The body can include an improved wet strength, which may be represented by wet flexure stress retention. In an embodiment, the body includes a wet flexure stress retention of at least 52%.

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ABRASIVE ARTICLES AND METHODS FOR FORMING SAME

TECHNICAL FIELD

The present invention relates to abrasive articles and methods of forming the abrasive articles.

5 BACKGROUND ART

Abrasive articles, such as abrasive wheels, can be used to remove materials from workpieces and may leave undesirable scratch marks on workpieces. In wet grinding processes, fluids are used to cool and lubricate grinding wheels and workpieces to remove debris and improve grinding efficiency. Wet retention abilities of grinding wheels affects consistency of wheel performance. The industry continues to demand improved abrasive articles.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings. The drawings are not necessarily to scale.

15 FIG. 1 includes a flow chart for forming an abrasive article.

FIG. 2 includes a graph of FTIR readouts of conventional bond precursor material and a bond precursor material in accordance with an embodiment.

FIG. 3 includes a graph of FTIR readouts of conventional abrasive article, an abrasive article sample in accordance with an embodiment, and a bond precursor material in accordance with embodiment.

FIG. 4 includes a graph of FTIR readouts of representative abrasive articles.

FIG. 5 includes a plot of FTIR absorption intensity versus contents of siloxane in bond materials of representative abrasive articles.

FIG. 6 includes a plot of scratch mark count versus scratch mark size of a set of wheel samples.

FIG. 7 includes a plot of scratch mark count versus scratch mark size of another set of wheel samples.

Skilled artisans appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The following description in combination with the figures is provided to assist in understanding the teachings disclosed herein. The following discussion will focus on specific implementations and embodiments of the teachings. This focus is provided to assist in
5 describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings. However, other teachings can certainly be used in this application.

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

Also, the use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise. For example, when
15 a single item is described herein, more than one item may be used in place of a single item. Similarly, where more than one item is described herein, a single item may be substituted for that more than one item.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be
25 limiting. To the extent that certain details regarding specific materials and processing acts are not described, such details may include conventional approaches, which may be found in reference books and other sources within the manufacturing arts.

Embodiments disclosed herein are related to abrasive articles including a body including abrasive particles contained within a bond material. The abrasive articles can have improved
30 performance and increased service life. Representative abrasive articles can include grinding

wheels having improved wet strength retention and capable of forming reduced number of scratch marks on a workpiece, as compared to conventional grinding wheels.

Further embodiments relate to abrasive articles having a body including a particular bond material. In an embodiment, the bond material can include a siloxane functional group (-Si-O-Si-) covalently bonded to a polymer backbone including aromatic rings connected by methylene bridges. In another embodiment, the bond material can have a FTIR signature peak at a wavelength in a range from 1258 cm^{-1} to 1265 cm^{-1} , such as at 1259 cm^{-1} or at 1261 cm^{-1} . In a particular embodiment, the bond material can include a polymer including a polydimethylsiloxane covalently bonded to a phenoxy. More particularly, the bond material can include a plurality of phenoxy, each of which is covalently bonded to a polydimethylsiloxane. The plurality of phenoxy can be covalently bonded to one another by methylene bridges.

Additional embodiments are related to a method of forming an abrasive article utilizing a bond precursor material. According to an embodiment, the bond precursor material can have a FTIR signature peak at a wavelength in a range from 1257 cm^{-1} to 1261 cm^{-1} . For example, the bond precursor material can have a FTIR signature peak at 1257 cm^{-1} . The bond precursor material can include a chemically modified resin. In an embodiment, the resin can include a phenolic resin, and the chemical modification can include a covalent bond between the phenolic resin and a siloxane functional group. In a particular embodiment, the chemically modified resin can include novolac resin chemically modified by polydimethylsiloxane. Use of the chemically modified phenolic resin can allow formation of abrasive articles with improved property and performance, such as improved ability of wet retention and reduced amount of scratch marks left on a workpiece.

FIG. 1 includes a flow chart of a method of forming an abrasive article in accordance with an embodiment. At step 101, a mixture can be made including a bond precursor material and abrasive particles. The mixture may also include one or more optional additives, including for example, secondary abrasive particles, fillers, reinforcing materials, and the like.

According to at least one embodiment, the bond precursor material can be present in the mixture in a certain content that can facilitate formation of an abrasive article with improved property and performance. For instance, the mixture can include at least 2.5 wt.% of the bond precursor material for a total weight of mixture, such as at least 3 wt.%, at least 5 wt.%, at least 8 wt.%, or at least 12 wt.%. In another instance, the mixture can include at most 25 wt.% of the

bond material for a total weight of the mixture, such as at most 22 wt.%, at most 20 wt.%, or at most 18 wt.%. In a further embodiment, the mixture can include the bond material in a content including any of the minimum and maximum percentages disclosed herein. For instance, the bond precursor material can be present in the mixture from 2.5 wt.% to 25 wt.% for a total weight of the mixture.

According to an embodiment, the bond precursor material can include an organic material, such as a natural organic material or synthetic organic material. An exemplary organic material can include a resin, such as phenolic resins, epoxy resins, polyester resins, polyurethanes, polyester, polyimide, polybenzimidazole, aromatic polyamide, modified phenolic resins (such as epoxy modified or phenolic resin blended with plasticizers, etc.), and the like, as well as any combination thereof. According to at least one embodiment, the bond precursor material can include a phenolic resin including novolac resin, resole resin, or any combination thereof.

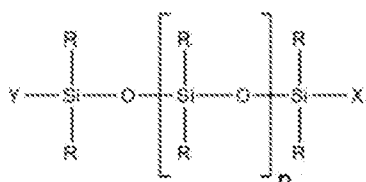
According to another embodiment, the bond precursor material can include a chemically modified resin. The chemical modification can include a covalent bond between the resin and a particular functional group that is different from a functional group of the resin. The particular functional group can be a unit of a molecule, and the resin can be chemically bonded to the molecule having the functional group. For instance, the modifying functional group can be directly or indirectly covalently bonded to the resin.

According to an embodiment, chemically modified resin can include a chemically modified phenolic resin. According to another embodiment, an exemplary modifying functional group can include a siloxane functional group (-Si-O-Si-). In a particular embodiment, chemically modified resin can consist essentially of chemically modified phenolic resin including at least one siloxane functional group. In another particular embodiment, the bond precursor material can include phenolic resin chemically modified by a molecule including a siloxane functional group. Particularly, chemically modified phenolic resin can include phenolic resin covalently bonded to a molecule including a siloxane functional group. The molecule can include a monomer, oligomer, polymer or a combination thereof. In another embodiment, the molecule can include a plurality of siloxane functional groups, such as repeating siloxane functional groups. According to a further embodiment, chemically modified phenolic resin can include chemically modified novolac resin, chemically modified resole resin, or a combination

thereof. According to a particular embodiment, chemically modified phenolic resin can include chemically modified novolac resin. More particularly, chemically modified phenolic resin can consist essentially of chemically modified novolac resin.

According to a particular embodiment, chemically modified novolac resin can include
 5 novolac resin covalently bonded to an oligomer including at least one siloxane functional group, novolac resin covalently bonded to a polymer including at least one siloxane functional group, or a combination thereof.

According to an embodiment, an exemplary molecule suitable for chemically modifying a resin can include an oligomer or polymer represented by the below formula. As used herein,
 10 the term, siloxane, is intended to refer to a molecule represented by the below formula.



R can include a methyl or phenyl group, X and Y can be the same or different and independently represent hydrogen atoms, hydrocarbyl groups, or alkoxy groups, and n can be at least one and up to 500 or higher. X, Y, or both can react with the resin to form a covalent bond
 15 between the resin and the molecule forming a chemically modified resin. For instance, X, Y, or both can react with a novolac resin such that the molecule can be covalently bonded to novolac resin. In at least one embodiment, the molecular can have a molecular weight of at least 500 Dalton. In another embodiment, at least one of R, X, and Y can be $-\text{CH}_3$. In a particular embodiment, the molecular can have a molecular weight of at least 500 Dalton, and each of R, X,
 20 and Y can be $-\text{CH}_3$.

According to an embodiment, X, Y, or both can react with a functional group of the resin forming a covalent bond. For example, X, Y or both can react to a hydroxyl group of a phenolic resin. In another embodiment, repeating siloxane functional groups may be bonded to phenolic resin through a methylene bridge. Particularly, the methylene group at the X or Y position can
 25 be directly bonded to an oxygen atom of the resin. In another embodiment, chemically modified resin can include polydimethylsiloxane covalently bonded to a novolac resin. For instance, the modified novolac resin can include covalent bond between a methylene bridge and a phenoxy, wherein the methyl bridge can be covalently bonded to a siloxane group. In a particular

embodiment, the modified resin can include a direct covalent bond between an oxygen atom directly bonded to a benzene ring and a methylene group bonded to a siloxane group.

In yet another embodiment, the bond precursor material can include a resin, and a chemically modified resin. For instance, the bond precursor material can include phenolic resin and phenolic resin chemically modified by a siloxane functional group. Particularly, the bond precursor material can include phenolic resin and chemically modified novolac resin. More particularly, the bond precursor material can include phenolic resin, such as novolac resin, resole resin, or a combination thereof, and novolac resin chemically modified by a siloxane functional group. In a particular embodiment, the bond precursor material can include a novolac resin, a siloxane chemically modified novolac resin, a resole resin, or any combination thereof. In another particular embodiment, the phenolic resin can include resole resin and chemically modified novolac resin.

According to an embodiment, the mixture can include a certain content of chemically modified resin that can facilitate formation of an abrasive article with improved property and performance. For instance, the chemically modified resin can be present in the mixture in a content of at least 1 wt.%, such as at least 2 wt.% or at least 3.5 wt.% or at least 5 wt.% or at least 6.5 wt.% or at least 7.5 wt.% for a total weight of the mixture. In another instance, the chemically modified resin can be present in the mixture in a content of at most 20 wt.%, such as at most 18 wt.% or at most 14 wt.% or at most 12 wt.% or at most 10 wt.% for a total weight of the mixture. In a further embodiment, the content of the chemically modified resin can be in a range including any of the minimum and maximum percentages noted herein, such as in a range from at least 1 wt.% to at most 20 wt.%. In a particular embodiment, the chemically modified resin can include siloxane chemically modified novolac resin, and accordingly, siloxane chemically modified novolac resin can have any of the contents noted herein.

According to an embodiment, the bond precursor material can include novolac resin covalently bonded to polydimethylsiloxane. In a particular embodiment, the chemically modified resin can consist essentially of novolac resin chemically modified by polydimethylsiloxane. For instance, chemically modified novolac resin can include polydimethylsiloxane covalently bonded to phenoxy. In this disclosure, polydimethylsiloxane is detected using Perkin Elmer Frontier Model FTIR with a Diamond/ZnSe Tip ATR probe. The resin samples in powder form can be analyzed directly under the probe using Diamond/ZnSe Tip

ATR probe. The spectra data of the samples are compared to data from know-it-all informatics ATR/IR library to determine what each peak of the spectra represents.

FIG. 2 includes FTIR spectra of conventional novolac resin, siloxane resin, and polydimethylsiloxane chemically modified novolac resin (SMR resin). As indicated in FIG. 2, siloxane resin demonstrated a signature peak at 1259 cm^{-1} , while SMR resin demonstrated a signature peak at 1257 cm^{-1} . The conventional resin did not demonstrate a peak at 1259 cm^{-1} or 1257 cm^{-1} .

According to an embodiment, the bond precursor material can include chemically modified resin in a content that can facilitate formation of an abrasive article with improved performance. In a non-limiting embodiment, chemically modified resin may have a content of at least 60 wt.% relative to a total weight of the bond precursor material, such as at least 70 wt.% or at least 75 wt.% or at least 80 wt.% or even at least 85 wt.% for the total weight of the bond precursor material. In another non-limiting embodiment, the chemically modified resin may not be greater than 95 wt.% of the total weight of the bond precursor material, such as not greater than 90 wt.% or not greater than 88 wt.%. It is to be understood that the content of the chemically modified resin can include any of the minimum and maximum percentages disclosed herein. In a further embodiment, the chemically modified resin can include novolac resin covalently bonded to siloxane functional groups. Particularly, the chemically modified resin can include novolac resins covalently bonded to siloxane, or more particularly, can consist essentially of siloxane chemically modified novolac resin. Accordingly, the content of siloxane chemically modified resin can include any of the contents noted for the chemically modified resin. In a particular embodiment, the siloxane chemically modified resin can include polydimethylsiloxane chemically modified novolac resin, or more particularly, can consist essentially of polydimethylsiloxane chemically modified novolac resin. In a more particular embodiment, the bond precursor material can include the polydimethylsiloxane chemically modified novolac resin in any of the contents noted for the chemically modified resin.

In a non-limiting embodiment, the bond precursor material can include a particular content of siloxane that is covalently bonded to the resin. In one embodiment, the bond precursor material can include at least 1 wt.% of the covalently bonded siloxane for the total weight of the bond precursor material, such as at least 1.5 wt.% or at least 2 wt.% or at least 2.5 wt.% or at least 3 wt.% or at least 3.5 wt.% or at least 4 wt.% or at least 4.5% or at least 5 wt.%

or at least 5.5 wt.% or at least 6 wt.% or at least 6.5 wt.% or at least 7 wt.% or at least 7.5 wt.% or at least 8 wt.% or at least 8.5 wt.% or at least 9 wt.% or at least 9.5 wt.% or at least 10 wt.% or at least 11 wt.% or at least 12 wt.% or at least 12.5 wt.% or at least 13 wt.% or at least 13.5 wt.% of the covalently bonded siloxane for the total weight of the bond precursor material.

5 Alternatively or additionally, the bond precursor material can include at most 30 wt.% of the covalently bonded siloxane for the total weight the bond precursor material, such as at most 29 wt.% or at most 28 wt.% or at most 27 wt.% or at most 26 wt.% or at most 25 wt.% or at most 24 wt.% or at most 23 wt.% or at most 22 wt.% or at most 21 wt.% or at most 20 wt.% or at most 19.5 wt.% or at most 19 wt.% or at most 18.5 wt.% or at most 18 wt.% of the covalently bonded
10 siloxane for the total weight of the bond precursor material. Moreover, the content of the covalently bonded siloxane can be in a range including any of the minimum and maximum values noted herein. For example, the bond precursor material can include the covalently bonded siloxane in a content in a range including at least 1 wt.% and at most 30 wt.%. In a particular embodiment, the covalently bonded siloxane can include polydimethylsiloxane, or more
15 particularly, can consist essentially of polydimethylsiloxane. Accordingly, the bond precursor material can include polydimethylsiloxane in any content noted for covalently bonded siloxane.

According to an embodiment, the bond precursor material can further include a conventional resin, such as a phenolic resin, in a content that can facilitate formation of an abrasive article with improved performance. For example, the resin may be present in the bond
20 precursor material in a content of at most 40 wt.%, or at most 30 wt.%, or at most 20 wt.%, or even at most 15 wt.% of the total weight of the bond precursor material. In yet another embodiment, the resin may be present for at least 5 wt.% or at least 10 wt.% or at least 12 wt.% of the total weight of the bond precursor material. It is to be understood the content of a conventional resin can include any of the minimum and maximum percentages disclosed herein.
25 In another embodiment, the phenolic resin can be in the liquid form.

In an embodiment, the bond precursor material can be in a powder or a liquid form, or include a combination thereof. For instance, the bond precursor material can include a powder phenolic resin and a liquid phenolic resin. In a further embodiment, the powder bond material can include chemically modified novolac resin, such as siloxane chemically modified novolac
30 resin, and the liquid bond material can include resole resin. The bond precursor material may be formed into a finally-formed bond material of an abrasive article by curing.

In another embodiment, the bond precursor material can include a curing agent or a cross-link agent. The curing or cross-link agent can include an amine. Exemplary amines can include ethylene diamine, ethylene triamine, methyl amines, or the like. In a particular embodiment, the curing or cross-linking agent can include hexamethylene tetramine. At
5 temperatures in excess of about 90 °C, some examples of the hexamethylene tetramine may form crosslinks to form methylene and dimethylene amino bridges that help cure the resin. The hexamethylene tetramine may be uniformly dispersed within the resin. More particularly, hexamethylene tetramine may be uniformly dispersed within resin regions as a cross-linking agent. In a more particular embodiment, the bond material can include a phenolic resin modified
10 with a curing or cross-linking agent. In a particular embodiment, the bond material can include novalac resin modified with a curing agent, such as hexamethylene tetramine. In a more particular embodiment, hexamethylene tetramine can be in a content of 5 wt.% to 15 wt.% of the total weight of the novalac resin. Even more particularly, the phenolic resin may contain resin regions with cross-linked domains having a sub-micron average size.

15 As disclosed herein, in addition to the bond material, the mixture can include abrasive particles. The abrasive particles can be in a content from 55 wt.% to 99 wt.% for a total weight of the mixture. In an embodiment, the abrasive particles can include materials such as oxides, carbides, nitrides, borides, carbon-based materials (e.g., diamond), oxycarbides, oxynitrides, oxyborides, and a combination thereof. According to one embodiment, the abrasive particles can
20 include a superabrasive material. The abrasive particles can include a material selected from the group of silicon dioxide, silicon carbide, alumina, zirconia, flint, garnet, emery, rare earth oxides, rare earth-containing materials, cerium oxide, sol-gel derived particles, gypsum, iron oxide, glass-containing particles, and a combination thereof. In another instance, abrasive particles may also include silicon carbide, brown fused alumina, white alumina, seeded gel abrasive, sintered
25 alumina with additives, shaped and sintered aluminum oxide, pink alumina, ruby alumina, electrofused monocrystalline alumina, alumina zirconia abrasives, extruded bauxite, sintered bauxite, cubic boron nitride, diamond, aluminum oxy-nitride, sintered alumina, extruded alumina, or any combination thereof. According to one particular embodiment, the abrasive particles can consist essentially of silicon carbide. According to another particular embodiment,
30 the abrasive particles can consist essentially of alumina, such as alpha alumina. According to another particular embodiment, the abrasive particles can consist essentially of nanocrystalline

alumina particles. The abrasive particles can have a Mohs hardness of at least 7, such as at least 8, or even at least 9.

The abrasive particles may have other particular features. For example, the abrasive particles can be shaped abrasive particles. According to at least one embodiment, the abrasive particles can include a two dimensional shape, a three-dimensional shape, or a combination thereof. Exemplary two dimensional shapes include regular polygons, irregular polygons, irregular shapes, triangles, partially-concave triangles, quadrilaterals, rectangles, trapezoids, pentagons, hexagons, heptagons, octagons, ellipses, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, and a combination thereof. In accordance with an embodiment, the abrasive particles can consist of any of the above noted two dimensional shapes. Exemplary three-dimensional shapes can include a polyhedron, a pyramid, an ellipsoid, a sphere, a prism, a cylinder, a cone, a tetrahedron, a cube, a cuboid, a rhombohedron, a truncated pyramid, a truncated ellipsoid, a truncated sphere, a truncated cone, a pentahedron, a hexahedron, a heptahedron, an octahedron, a nonahedron, a decahedron, a Greek alphabet letter, a Latin alphabet character, a Russian alphabet character, a Kanji character, complex polygonal shapes, irregular shaped contours, a volcano shape, a monostatic shape, and a combination thereof. A monostatic shape can be a shape with a single stable resting position. In accordance with another embodiment, the abrasive particles can consist of any of the above noted three dimensional shapes. In a particular embodiment, the shaped abrasive particles can include a triangular two-dimensional shape. In another particular embodiment, the shaped abrasive particles can include a partially-concave triangular two-dimensional shape. The shaped abrasive particles and methods of forming can be found in US2013/0236725 A1 by Doruk O. Yener, et al. and US 2012/0167481 by Doruk O. Yener, et al., both of which are incorporated herein by reference in their entireties.

In a particular embodiment, the abrasive particles may have an elongated shape. In a further embodiment, the abrasive particles may have an aspect ratio, defined as a ratio of the length:width of at least about 1:1, wherein the length is the longest dimension of the particle and the width is the second longest dimension of the particle (or diameter) perpendicular to the dimension of the length. In other embodiments, the aspect ratio of the abrasive particles can be at least about 2:1, such as at least about 2.5:1, at least about 3:1, at least about 4:1, at least about

5:1, or even at least about 10:1. In one non-limiting embodiment, the abrasive particles may have an aspect ratio of not greater than about 5000:1.

According to another particular embodiment, at least a portion of the abrasive particles may include shaped abrasive particles as disclosed for example, in US 2015/0291865 by Kristin Brender, et al., US 2015/0291866 by Christoher Arcona et al., and US 2015/0291867 by Kristin Brender, et al., all of which are incorporated herein by reference in their entireties. Shaped abrasive particles are formed such that each particle has substantially the same arrangement of surfaces and edges relative to each other for shaped abrasive particles having the same two-dimensional and three-dimensional shapes. As such, shaped abrasive particles can have a high shape fidelity and consistency in the arrangement of the surfaces and edges relative to other shaped abrasive particles of the group having the same two-dimensional and three-dimensional shape. By contrast, non-shaped abrasive particles can be formed through different process and have different shape attributes. For example, non-shaped abrasive particles are typically formed by a comminution process, wherein a mass of material is formed and then crushed and sieved to obtain abrasive particles of a certain size. However, a non-shaped abrasive particle will have a generally random arrangement of the surfaces and edges, and generally will lack any recognizable two-dimensional or three dimensional shape in the arrangement of the surfaces and edges around the body. Moreover, non-shaped abrasive particles of the same group or batch generally lack a consistent shape with respect to each other, such that the surfaces and edges are randomly arranged when compared to each other. Therefore, non-shaped grains or crushed grains have a significantly lower shape fidelity compared to shaped abrasive particles.

In at least one embodiment, the abrasive particles can include crystalline grains (i.e., crystallites), and may consist entirely of a polycrystalline material made of crystalline grains. In particular instances, the abrasive particles can include crystalline grains having a median grain size of not greater than 1.2 microns. In other instances, the median grain size can be not greater than 1 micron, such as not greater than 0.9 microns or not greater than 0.8 microns or even not greater than 0.7 microns. However, the nanocrystalline alumina particles may have an average crystallite size of not greater than 0.15 microns, such as not greater than 0.14 microns, not greater than 0.13 microns or even not greater than 0.12 microns. According to one non-limiting embodiment, the median grain size of the abrasive particles can be at least 0.01 microns, such as at least 0.05 microns or at least 0.1 microns or at least 0.2 microns or even at least 0.4 microns.

It will be appreciated that the median grain size of the abrasive particles can be within a range between any of the minimum and maximum values noted above. The median grain size is measured by an uncorrected intercept method by SEM micrographs.

In accordance with an embodiment, the abrasive particles can have an average particle size, as measured by the largest dimension (i.e., length) of at least about 100 microns. In fact, the abrasive particles can have an average particle size of at least about 150 microns, such as at least about 200 microns, at least about 300 microns, at least about 400 microns, at least about 500 microns, at least about 600 microns, at least about 700 microns, at least about 800 microns, or even at least about 900 microns. Still, the abrasive particles of the embodiments herein can have an average particle size that is not greater than about 5 mm, such as not greater than about 3 mm, not greater than about 2 mm, or even not greater than about 1.5 mm. It will be appreciated that the abrasive particles can have an average particle size within a range between any of the minimum and maximum values noted above.

According to an embodiment, the mixture and the resulting abrasive article can include a blend of abrasive particles. The blend of abrasive particles can include a first type of abrasive particle and a second type of abrasive particle that is distinct from the first type of abrasive particle in at least one aspect, such as particle size, grain size, composition, shape, hardness, friability, toughness, and the like. For example, in one embodiment, the first type of abrasive particle can include a premium abrasive particle (e.g., fused alumina, alumina-zirconia, seeded sol gel alumina, shaped abrasive particle, etc.) and the second type of abrasive particle can include a diluent abrasive particle. According to a non-limiting embodiment, the secondary abrasive particles can include alumina oxide, silicon carbide, cubic boron nitride, diamond, flint and garnet grains, and any combination thereof. In other non-limiting embodiments, the blend may include a third type of abrasive particles that may include a conventional abrasive particle or a shaped abrasive particle. The third type of abrasive particles may include a diluent type of abrasive particles having an irregular shape, which may be achieved through conventional crushing and comminution techniques. The third type of abrasive particles may be distinct from the first type of abrasive particles and the second type of abrasive particles in composition or any other aspect disclosed in embodiments herein.

The blend of abrasive particles can include a first type of abrasive particles present in a first content (C1), which may be expressed as a percentage (e.g., a weight percent) of the first

type of abrasive particles as compared to the total content of particles of the blend. For example, in certain instances, the blend can be formed such that the first content (C1) may be not greater than 90% of the total content of the blend. In another embodiment, the first content may be less, such as not greater than 85% or not greater than 80% or not greater than 75%. Still, in one non-limiting embodiment, the first content of the first type of abrasive particles may be present in at least 10% of the total content of the blend, such as at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, or at least 50%. It will be appreciated that the first content (C1) may be present within a range between any of the minimum and maximum percentages noted above.

Furthermore, the blend of abrasive particles may include a second content (C2) of the second type of abrasive particles, expressed as a percentage (e.g., a weight percent) of the second type of abrasive particles relative to the total weight of the blend. The second content can be the same as or different from the first content. For example, the second content (C2) may be not greater than 55% of the total content of the blend, such as not greater than 50%, such as not greater than 40%, not greater than 35%, not greater than 30%, or not greater than 25%. Still, in one non-limiting embodiment, the second content (C2) may be present in an amount of at least about 1% of the total content of the blend. For example, the second content may be at least 5%, such as at least 8%, at least 10%, or at least 12%. It will be appreciated that the second content (C2) can be within a range between any of the minimum and maximum percentages noted above.

In some embodiments, the blend of abrasive particles may include a third content (C3) of the third type of abrasive particles, expressed as a percentage (e.g., a weight percent) of the third type of abrasive particles relative to the total weight of the blend. The third content can be the same as or different from the first content, the second content, or both. For example, the third content (C3) may be not greater than 50% of the total content of the blend, such as not greater than 45%, such as not greater than 40%, not greater than 35%, not greater than 30%, not greater than 25%, or not greater than 20%. Still, in one non-limiting embodiment, the third content (C3) may be present in an amount of at least about 1% of the total content of the blend. For example, the third content may be at least 3%, such as at least 5%, at least 8%, or at least 10%. It will be appreciated that the third content (C3) can be within a range between any of the minimum and maximum percentages noted above.

As described herein, other materials, such as a filler, can be included in the mixture. The filler may or may not be present in the finally-formed abrasive article. An exemplary filler can include powders, granules, spheres, fibers, pore formers, hollow particles, and a combination thereof. Filler can include a material selected from the group consisting of sand, bubble alumina, chromites, magnetite, dolomites, bubble mullite, borides, titanium dioxide, carbon products, silicon carbide, wood flour, clay, talc, hexagonal boron nitride, molybdenum disulfide, feldspar, nepheline syenite, glass spheres, glass fibers, CaF_2 , KBF_4 , Cryolite (Na_3AlF_6), potassium Cryolite (K_3AlF_6), pyrite, ZnS , copper sulfide, mineral oil, fluorides, wollastonite, mullite, steel, iron, copper, brass, bronze, tin, aluminum, kyanite, alusite, garnet, quartz, fluoride, mica, nepheline syenite, sulfates (e.g., barium sulfate), carbonates (e.g., calcium carbonate), titanates (e.g., potassium titanate fibers), rock wool, clay, sepiolite, iron sulfide (e.g., Fe_2S_3 , FeS_2 , or a combination thereof), potassium fluoroborate (KBF_4), zinc borate, borax, boric acid, fine alundum powders, P15A, cork, glass spheres, silica microspheres (Z-light), silver, Saran™ resin, paradichlorobenzene, oxalic acid, alkali halides, organic halides, attapulgite, carbonates, calcium carbonate, saran, phenoxy resin, CaO , K_2SO_4 , mineral wool, MnCl_2 , KCl , and a combination thereof. In accordance with another embodiment, the filler can include a material selected from the group consisting of an antistatic agent, a lubricant, a porosity inducer, coloring agent, and a combination thereof. In particular instances wherein the filler is particulate material, it may be distinct from the abrasive particles, being significantly smaller in average particle size than the abrasive particles.

According to a particular embodiment, the mixture can include a filler including barium sulfate. According to another particular embodiment, the mixture can include a filler including cryolite. According to still another particular embodiment, the mixture can include a filler including at least one of barium sulfate and cryolite, and one or more of any other fillers disclosed herein.

After forming the mixture with the desired components and shaping the mixture in desired processing apparatus, the process can continue to step 102 by treating the mixture to form a finally-formed abrasive article. Some suitable examples of treating can include heating, curing, polymerization, pressing, and a combination thereof. Curing can take place in the presence of heat. For example, the mixture can be held at a final cure temperature for a period of time, such as between 6 hours and 48 hours, between 10 and 36 hours, or until the mixture

reaches the cross-linking temperature or desired density is obtained. Selection of the curing temperature depends, for instance, on factors such as the type of bonding material employed, strength, hardness, and grinding performance desired. According to certain embodiments, the curing temperature can be in the range including at least 150 °C to not greater than 250 °C. In more specific embodiments employing organic bonds, the curing temperature can be in the range including at least 150 °C to not greater than 230 °C. Polymerization of phenol based resins may occur at a temperature in the range of including at least 110 °C and not greater than 225 °C. Resole resins can polymerize at a temperature in a range of including at least 140 °C and not greater than 225 °C. Certain novolac resins suitable for the embodiments herein can polymerize at a temperature in a range including at least 130 °C and not greater than 195 °C.

After finishing the treating process, the abrasive article is formed including abrasive particles contained within the bond material. In a particular embodiment, the abrasive article can be a bonded abrasive article. The bonded abrasive article can include a body including abrasive grains contained in a three-dimensional matrix of the bond material. The body may be formed into any suitable shape as known by those of skill in the art, including but not limited to, abrasive wheels, cones, hones, cups, flanged-wheels, tapered cups, segments, mounted-point tools, discs, thin wheels, large diameter cut-off wheels, and the like.

According to an embodiment, the bonded abrasive can include a body having a certain content of the bond material relative to a total volume of the body, which may facilitate improved formation and/or performance of an abrasive article. For example, the content of the bond material can be at least 5 vol%, such as at least 10 vol%, at least 20 vol%, at least 30 vol%, at least 35 vol%, or at least 40 vol% for the total volume of the body. For another instance, the content of the bond material may be not greater than 55 vol%, such as not greater than 50 vol%, or not greater than 45 vol%, not greater than 40 vol%, or not greater than 35 vol%, not greater than 30 vol%, or not greater than 25 vol%. It is to be appreciated that the content of the bond material can be within a range including any of the minimum to maximum percentages noted above. For example, the content of the bond material in the body can be within a range of within a range of 5 vol% to 55 vol%, or within a range of 10 vol% to 35 vol%.

According to an embodiment, the bond material can include a polymer including a covalently bonded siloxane functional group. According to a further embodiment, the polymer can include repeating siloxane functional groups covalently bonded to an oxygen atom. In

another embodiment, the bond material can include a plurality of oxygen atoms, each of which is bonded to a siloxane functional group. In a further embodiment, the bond material can include a polymer including repeating siloxane functional groups covalently bonded to phenoxy. In still another embodiment, the bond material can include a polymer including a plurality of phenoxy covalently bonded to one another by a methylene bridge, wherein at least one of the phenoxy is covalently bonded to a siloxane group through the oxygen atom of the phenoxyl. In yet another embodiment, the bond material can include a polymer including polydimethylsiloxane covalently and directly bonded to the oxygen atom of phenoxyl. In a particularly embodiment, the polymer can include a direct covalent bond between a methylene group and an oxygen atom, wherein the methylene group is directly and covalently bonded to one of the repeating siloxane groups and the oxygen atom is directly and covalently bonded to a benzene ring, and more particularly, the polymer can include a plurality of the direct covalent bonds. In another particular embodiment, the bond material can include a polymer including repeating benzene rings covalently bonded to one another through a methylene bridge and each of a plurality of the repeating benzene rings are covalently bonded to an oxygen atom that is covalently bonded to siloxane group through a methylene bridge, and more particularly, the methylene bridge is directly and covalently bonded to one of the repeating siloxane functional groups. In a particular embodiment, the polymer can include a plurality of phenoxyl, each of which is covalently bonded to a polydimethylsiloxane.

According to an embodiment, the bond material can include a polymer including polydimethylsiloxane covalently bonded to a benzene ring. According to a further embodiment, polydimethylsiloxane can be covalently bonded to phenoxy. In a particular embodiment, the polymer can include benzene rings covalently bonded to one another through a methylene bridge, and at least some of the benzene rings can be covalently bonded to polydimethylsiloxane through oxygen atoms bonded to benzene rings.

In this disclosure, polydimethylsiloxane is detected in abrasive articles using Perkin Elmer Frontier Model FTIR with a Diamond/ZnSe Tip ATR probe. A segment of an abrasive article can be removed for analysis by FTIR. The sample can be crushed, and 10 grams of crushed powder can be sieved to remove abrasive particles. 50mg of sieved powder can be analyzed directly under the probe. The spectra data can be compared to data from know-it-all informatics ATR/IR library to determine what each peak of the spectra represents.

The bond material can have a FTIR signature peak. In one embodiment, the signature peak can appear at a wavelength in a range from 1258 cm^{-1} to 1275 cm^{-1} . In another embodiment, the signature peak can appear at a wavelength in a range from 1258 cm^{-1} to 1265 cm^{-1} . FIG. 3 includes FTIR spectra of a conventional wheel C1 formed with rubber modified resin (RMR wheel), representative wheel (SMR wheel), and the siloxane chemically modified resin (SMR resin) used in formation of the representative wheel. As indicated in the figure, the SMR wheel sample demonstrated a signature peak of polydimethylsiloxane at 1259 cm^{-1} , while the RMR sample demonstrated no peak at 1259 cm^{-1} . FIG. 4 includes FTIR spectra of wheels formed with bond materials including different contents of covalently bonded polydimethylsiloxane. The signature peaks are at 1261 cm^{-1} .

According to an embodiment, the bond material can include a certain content of the covalently bonded siloxane, which can facilitate improved formation and performance of the abrasive article. In one embodiment, the bond material can include at least 1 wt.% of the covalently bonded siloxane for the total weight of the bond material, such as at least 1.5 wt.% or at least 2 wt.% or at least 2.5 wt.% or at least 3 wt.% or at least 3.5 wt.% or at least 4 wt.% or at least 4.5 wt.% or at least 5 wt.% or at least 5.5 wt.% or at least 6 wt.% or at least 6.5 wt.% or at least 7 wt.% or at least 7.5 wt.% or at least 8 wt.% or at least 8.5 wt.% or at least 9 wt.% or at least 9.5 wt.% or at least 10 wt.% or at least 11 wt.% or at least 12 wt.% or at least 12.5 wt.% or at least 13 wt.% or at least 13.5 wt.% of the covalently bonded siloxane for the total weight of the bond material. Alternatively or additionally, the bond material can include at most 30 wt.% of the covalently bonded siloxane for the total weight the bond material, such as at most 29 wt.% or at most 28 wt.% or at most 27 wt.% or at most 26 wt.% or at most 25 wt.% or at most 24 wt.% or at most 23 wt.% or at most 22 wt.% or at most 21 wt.% or at most 20 wt.% or at most 19.5 wt.% or at most 19 wt.% or at most 18.5 wt.% or at most 18 wt.% of the covalently bonded siloxane for the total weight of the bond material. Moreover, the content of the covalently bonded siloxane can be in a range including any of the minimum and maximum values noted herein. For example, the bond material can include a content of the covalently bonded siloxane in a range including at least 1 wt.% and at most 30 wt.%. In a particular embodiment, the covalently bonded siloxane can include polydimethylsiloxane, or more particularly, can consist essentially of polydimethylsiloxane. Accordingly, the bond material can include polydimethylsiloxane in any content noted herein for covalently bonded siloxane. Referring to FIG. 5, a linear correlation

between absorption intensity at 1261 cm^{-1} and contents of polydimethylsiloxane relative to the total weight of the bond material is illustrated.

According to an embodiment, the bonded body of the abrasive article can include a certain content of the abrasive particles, which may facilitate improved formation and/or performance of an abrasive article. For instance, a content of the abrasive particles can be at least 8 vol%, such as at least 10 vol%, at least 12 vol%, at least 14 vol%, at least 16 vol%, at least 18 vol%, at least 20 vol%, at least 25 vol%, at least 30 vol%, or even at least 35 vol%. In another instance, a content of the abrasive particles within the bonded abrasive body may be not greater than 65 vol%, such as not greater than 64 vol%, not greater than 62 vol%, not greater than 60 vol%, not greater than 58 vol%, not greater than 56 vol%, not greater than about 54 vol%, not greater than 52 vol%, not greater than 50 vol%, not greater than 48 vol%, not greater than 46 vol%, not greater than 44 vol%, not greater than 42 vol%, not greater than 40 vol%, not greater than 38 vol%, not greater than 36 vol%, not greater than 34 vol%, not greater than 32 vol%, not greater than 30 vol%, or greater than 28 vol%, or not greater than 26 vol. It will be appreciated that a content of the abrasive particles can be within a range including any of the minimum and maximum percentages noted above. For example, a content of the abrasive particles in the body can be within a range of 8 vol% to 65 vol%, within a range of 12 vol% to 62 vol%, within a range of 20 vol% to 58 vol%, or within a range of 26 vol% to 52 vol%.

The body of the abrasive article can be formed to have certain porosity. In an embodiment, porosity can be at least 1 vol% for a total volume of the body. For example, porosity can be at least 3 vol% or at least 5 vol% or at least 8 vol%, at least 10 vol%, at least 12 vol%, at least 14 vol%, at least 16 vol%, at least 18 vol%, at least 20 vol%, at least 25 vol%, at least 30 vol%, or at least 40 vol. In another embodiment, porosity of the body may be not greater than 60 vol%. For instance, porosity may be not greater than 55 vol%, not greater than 50 vol%, not greater than 45 vol%, or not greater than 40 vol%. It will be appreciated that porosity of the body can be within a range including any of the minimum to maximum percentages noted above. For example, porosity of the body can be within a range of 5 vol% to 60 vol%, within a range of 8 vol% to 55 vol%, or within a range of 10 vol% to 40 vol%.

The porosity of the body can be in various forms. For instance, the porosity can be closed, open, or include closed porosity and open porosity. In an embodiment, the porosity can include a type of porosity selected from the group consisting of closed porosity, open porosity,

and a combination thereof. In another embodiment, the majority of the porosity can include open porosity. In a particular embodiment, all of the porosity can essentially be open porosity. Still, in another embodiment, the majority of the porosity can include closed porosity. For example, all of the porosity can be essentially closed porosity.

5 The body can include pores having certain average pore sizes. In an embodiment, the average pore size may be not greater than 500 microns, such as not greater than 450 microns, not greater than 400 microns, not greater than 350 microns, not greater than 300 microns, not greater than 250 microns, not greater than 200 microns, not greater than 150 microns, or not greater than 100 microns. In another embodiment, the average pore size can be at least 0.01 microns, at least 0.1 microns, or at least 1 micron. It will be appreciated that the body can have an average pore size within a range including any of the minimum to maximum values noted above. For example, the average pore size of the body can be within a range of 0.01 microns to 500 microns, within a range of 0.1 microns to 350 microns, or within a range of 1 micron to 250 microns.

 According to an embodiment, the bonded abrasive can include a body having improved wet strength retention. In at least one embodiment, wet strength retention can be represented by wet flexural stress retention. The body of the bonded abrasive article can include a wet flexural stress retention of at least 52%, such as at least 53%, at least 54%, at least 55%, at least 56%, at least 57%, at least 58%, or at least 59%. In at least one other embodiment, the body may include a wet flexural stress retention of not greater than 65%, such as not greater than 64%, not greater than 63%, such as not greater than 62%, not greater than 61%, such as not greater than 60%, or not greater than 59.5%. It is to be appreciated that the body can have a wet flexural stress retention in a range including any of the minimum and maximum percentages noted herein. For instance, the body can have a wet flexural stress retention in a range including at least 52% and not greater than 65%.

25 Wet flexural stress retention can be measured using the formula of $WR = (MOR_{wet} / MOR_{dry}) \times 100\%$, where WR represents wet flexural stress retention, MOR_{wet} is the modulus of rupture (MOR) of a sample after wet treatment, and MOR_{dry} is the MOR of the sample prior to wet treatment. MOR_{dry} and MOR_{wet} can be determined using the test method disclosed in the following paragraph.

30 MOR of an abrasive article is tested in accordance with the three point bending method. The test is performed on a 100kN Cell Instron testing machine with a displacement rate of

1mm/min at room temperature (e.g., 15 to 25 °C). A test sample can be a portion of the abrasive article and has a size of 25mmx25mmx100mm, such as a segment cut from a grinding wheel.

MOR_{dry} is tested on dry samples without wet treatment. Other samples cut from the same abrasive article as the dry samples are immersed in boiling water for 2 hours and then cooled to room temperature prior to the MOR test to obtain MOR_{wet}.

According to an embodiment, the bonded abrasive article of embodiments herein can be capable of generating a decreased number of scratch marks on a workpiece in a grinding test, comparing to a corresponding conventional abrasive article made with a different bond precursor material but otherwise being the same and tested in the same condition. The grinding test is performed on forged steel with 3 wt.% to 5 wt.% of Cr. Wheels having the width of Ø350 mm x 25 mm are mounted on CNC cylindrical grinders powered with 5.5 kW grinding motor, and the wheel speed is 33 m/s. The mode of grinding is traverse, and volumetric removal rate is targeted in a range from 1.8 to 9 mm³/s/mm. Power drawn during grinding is measured in real-time along with surface finish of the workpiece and change of diameter of the workpiece.

In this disclosure, the lengths and count of scratch marks on a workpiece is determined as follows. A blue paste (Permatex® Prussian blue #80038) is applied to the ground surface of a workpiece. Under white lights, the scratch marks become visible, as the blue paste fills into the depths of the scratches. An area of 10 mm x 10 mm of the surface is marked and a picture of the area is taken under an Olympus stereo microscope. The image is processed by the Essentials software provided by the Olympus stereo microscope. The scratches within the marked area are counted and the lengths of these scratches are measured by the software.

In an embodiment, the bonded abrasive article can generate at least 30% less scratch marks compared to the corresponding conventional abrasive article under the same test condition, such as at least 40% less or 50% less. The decrease of scratch marks is determined by dividing the difference between the total counts of scratch marks against the total count of the corresponding conventional wheel. In another embodiment, the decrease can be at most 50%.

Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein. After reading this specification, skilled artisans will appreciate that those aspects and embodiments are only illustrative and do not limit the scope of the present invention. Embodiments may be in accordance with any one or more of the embodiments as listed below.

Embodiment 1. A bonded abrasive article, comprising:

a body including abrasive particles contained within a bond material,

wherein the bond material comprises a polymer including a plurality of aromatic rings that are covalently bonded to one another and a siloxane functional group covalently bonded to the plurality of aromatic rings.

Embodiment 2. A bonded abrasive article, comprising:

a body including abrasive particles contained within a bond material,

wherein the body comprises a wet flexural stress retention of at least 52%.

Embodiment 3. A bonded abrasive article, comprising:

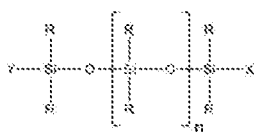
a body including abrasive particles contained within a bond material,

wherein the bond material has a FTIR signature peak at a wavelength from 1258 cm^{-1} to 1275 cm^{-1} .

Embodiment 4. The bonded abrasive article of any one of embodiments 1 to 3, wherein

the bond material comprises a polymer including a siloxane that is covalently bonded to a

plurality of benzene rings, wherein the siloxane is represented by a formula:



wherein R includes a methyl or phenyl group, X and Y independently represents hydrogen atoms, a hydrocarbyl group, or an alkoxy group, and n is at least one.

Embodiment 5. The bonded abrasive article of any one of embodiments 1 to 4, wherein

the bond material comprises a polymer including polydimethylsiloxane covalently bonded to a phenoxy.

Embodiment 6. The bonded abrasive article of any one of embodiments 1 to 5, wherein

the bond material comprises polydimethylsiloxane covalently bonded to an oxygen atom,

wherein the oxygen atom is directly and covalently bonded to a benzene ring.

Embodiment 7. The bonded abrasive article of any one of embodiments 1 to 6, wherein

the bond material comprises a polymer including polydimethylsiloxane covalently bonded to a backbone including benzene rings covalently bonded to one another by a methylene bridge.

Embodiment 8. The bonded abrasive article of any one of embodiments 1 to 7, wherein the body comprises a wet flexural stress retention of at least 52%, at least 53%, at least 54%, at least 55 %, at least 56 %, or at least 57%, and not greater than 80%.

Embodiment 9. The bonded abrasive article of any one of embodiments 1 to 8, wherein
5 the body comprises the bond material in a content in a range of 5 vol% to 55 vol% for a total volume of the body.

Embodiment 10. The bonded abrasive article of any one of embodiments 1 to 9, wherein the body comprises the abrasive particles in a content in a range of 8 vol% to 65 vol% for a total volume of the body.

10 Embodiment 11. The abrasive article of any one of embodiments 1 to 10, wherein the body comprises a porosity in a range of 5 vol% to 60 vol% for a total volume of the body.

Embodiment 12. The abrasive article of any one of embodiments 1 to 11, wherein the body comprises a filler including barium sulfate, cryolite, or any combination thereof.

Embodiment 13. A process of forming an abrasive article, comprising:
15 forming a green body with a mixture comprising abrasive particles and a bond precursor material,
wherein the bond precursor material comprises a resin having a FTIR signature peak at 1257 cm^{-1} to 1261 cm^{-1} .

Embodiment 14. The process of embodiment 13, wherein the bond precursor material
20 comprises a phenolic resin covalently bonded to a siloxane functional group.

Embodiment 15. The process of any one of embodiments 12 to 14, wherein the bond precursor material comprises polydimethylsiloxane covalently bonded to phenoxy.

Embodiment 16. The process of any one of embodiments 13 to 15, wherein the mixture
25 comprises the abrasive particles in a content from 55 wt.% to 99 wt.% for a total weight of the mixture.

Embodiment 17. The process of any one of embodiments 13 to 16, wherein the mixture comprises the bond precursor material in a content from 2.5 wt.% to 25 wt.% for a total weight of the mixture.

Embodiment 18. The process of any one of embodiments 13 to 17, wherein the mixture
30 comprises the resin in a content from 1 wt.% to 20 wt.% for a total weight of the mixture.

Embodiment 19. The process of any one of embodiments 13 to 18, wherein the mixture comprises a filler including barium sulfate, cryolite, or a combination thereof.

Embodiment 20. The process of any one of embodiments 13 to 19, wherein the mixture comprises a filler in a content from 0.1 wt.% to 20 wt.% for a total weight of the bond material.

5 Embodiment 21. The process of any one of embodiments 13 to 20, wherein the bond precursor material comprises siloxane that is covalently bonded to an aromatic ring in a content of at least 1 wt.% and at most 30 wt.% for a total weight of the bond precursor material.

10 Embodiment 22. The process of any one of embodiments 13 to 21, wherein the bond precursor material comprises polydimethylsiloxane that is covalently bonded to a phenoxy radical in a content of at least 1 wt.% and at most 30 wt.% for a total weight of the bond precursor material.

Embodiment 23. The bonded abrasive article of any one of embodiments 1 to 12, wherein the bond material comprises siloxane that is covalently bonded to aromatic rings in a content of at least 1 wt.% and at most 30 wt.% for a total weight of the bond material

15 Embodiment 24. The bonded abrasive article of any one of embodiments 1 to 12 and 23, wherein the bond material comprises polydimethylsiloxane that is covalently bonded to a phenoxy radical in a content of at least 1 wt.% and at most 30 wt.% for a total weight of the bond material.

20 Embodiment 25. The bonded abrasive article of any one of embodiments 1 to 12 and 22 to 24, wherein the bond material comprises a FTIR signature peak at a wavelength of 1259 cm^{-1} .

Embodiment 26. The bonded abrasive article of any one of embodiments 1 to 12 and 22 to 24, wherein the bond material comprises a FTIR signature peak at a wavelength of 1261 cm^{-1} .

Examples

Example 1

25 Representative bonded abrasive wheels S1 and conventional wheels C1 were formed. The abrasive grains were first mixed with liquid resole in a mixing bowl for 2 to 7 minutes or until all of the grains were wet and coated by the liquid resole resin. The wet abrasive grains were then combined with the rest of the bond material. The mixture of each sample was poured into a mold, and cold pressed. The samples were then removed from the molds and heat treated
30 in a furnace at $160\text{ }^{\circ}\text{C}$ for the bond material to cure. The mixture compositions for wheels S1

and C1 are disclosed in Table 1 and 2 below, respectively. Each of wheels S1 and C1 included 85 wt.% of abrasive particles, 10 wt.% of bond material, and 5 vol% of pores.

As noted below, the wheels S1 and C1 were made using the same compositions except that a conventional, nitrile rubber modified novolac resin (RMR) used to form C1, while siloxane chemically modified novolac resin (SMR) was used to make S1. Wheel S1 included 13.5 wt.% of siloxane for the total weight of the bond material. All of the wheels had the dimension of 350mm (dia)x127mm (bore dia) x24mm(thickness), and sections of the dimension of 25mm x 25mm x 100mm were cut and tested for the wet retention ability as disclosed herein.

Table 1 Mixture Composition of Sample S1

Composition	Components	wt. %
Abrasive particles	Norton Quantum 80	40.614
	39C 80 (SiC having a grit size of 80)	3.287
	39C 90 (SiC having a grit size of 90)	44.901
Bond material	SMR	8.3
	Resole	2.465
	Tri Decyl Alcohol	0.183
	Castor oil	0.210

Table 2 Mixture Composition of Sample C1

Composition	Components	wt. %
Abrasive particles	Norton Quantum 80	40.614
	39C 80 (SiC having a grit size of 80)	3.287
	39C 90 (SiC having a grit size of 90)	44.901
Bond material	RMR	8.3
	Resole	2.465
	Tri Decyl Alcohol	0.183
	Castor oil	0.210

MOR_{dry} and MOR_{wet} of the S1 and C1 samples were tested prior to and after wet treatment in accordance with embodiments disclosed herein. The average values of the MOR of a group of 3 S1 samples and a group of 3 C1 samples are included in Table 3. Samples S1 had higher MOR prior to and after wet treatment, as compared to C1 samples. S1 samples also demonstrated higher wet strength retention represented by wet flexural stress retention.

Table 3 Wet Flexural Stress Retention

Sample	MOR _{dry} (MPa)	MOR _{wet} (MPa)	Wet Flexural Stress Retention (%)
S1	43.91	26	59.2
C1	13.85	7	50.5

Water uptake of samples S1 and C1 were measured. Weight of each sample was measured prior to and after wet treatment to determine the weight change. Water uptake is measured using the formula: $W_U = [(W_{wet} - W_{dry}) / W_{dry}] \times 100\%$. W_U represents water uptake, W_{dry} represents the weight of a sample prior to wet treatment, and W_{wet} represents the weight of the same sample after wet treatment. Three samples per group were tested, and the average of water uptake of each group is included in Table 4. S1 samples had lower average uptake compared to C1 samples, 7.03% vs. 14.231%.

Table 4 Water Uptake

Sample	W _{dry} (g)	W _{wet} (g)	Weight Change (g)	Water Uptake (%)
S1	113.7	122.3	8.6	7.03
C1	100.65	117.35	16.7	14.231

Example 2

Additional wheel samples were formed in a similar manner as disclosed in Example 1. The grinding test was performed on the samples, and counts and lengths of scratch marks were determined as disclosed herein. The mixture composition of representative wheel sample S2 is included in Table 5, and conventional wheel sample C2 was formed with the mixture having the same composition as S2 except siloxane modified resin was replaced with conventional rubber modified resin.

Table 5 Composition of S2

Composition	Components	Wt. %
Bond	LIQUID RESIN	1.616
	Tri Decyl Alcohol	0.257
	Siloxane modified resin	9.157
	Castor Oil	0.21
Abrasive particles	38A-White Al ₂ O ₃ (180 Grit)	88.76

The mixture composition of representative wheel sample S3 is included in Table 6, and conventional wheel sample C3 was formed with the mixture having the same composition as A48 except siloxane modified resin was replaced with conventional rubber modified resin. Each of the bond materials of S2 and S3 included 13.5 wt.% of siloxane for the total weight of the respective bond material.

Table 6 Composition of S3

Composition	Components	WT. %
Bond	LIQUID RESIN	1.185
	Tri Decyl Alcohol	0.299
	Siloxane modified resin	8.691
	Castor Oil	0.199
	BaSO ₄	7.535
Abrasive particles	ABRASIVE (60 grit Al ₂ O ₃)	81.99

FIG. 6 includes a plot of scratch numbers versus sizes of samples C2 and S2. Wheel C2 generated 93 scratch marks having length from 300 microns to 1200 microns, while wheels S2 generated 44 scratch marks in the same length range. FIG. 5 includes a plot of scratch numbers versus sizes of samples S3 and C3. Wheels C3 generated 94 scratch marks compared to 63 by S3 in a length range of 300 microns to 1500 microns.

Example 3

Additional wheel samples were formed in a similar manner as disclosed in Example 1. The wheel samples included different contents of covalently bonded polydimethylsiloxane as noted in Table 7 below. Segments of the samples were cut, prepared and analyzed for FTIR

spectra as described in this disclosure. FIG. 4 includes an illustration of the FTIR spectra of samples S4 to S7, demonstrating signature peaks at 1261 cm^{-1} .

Table 7

Samples	Content of polydimethylsiloxane
S4	1.5 wt.%
S5	7.5 wt.%
S6	11.25 wt.%
S7	13.75 wt.%

The present embodiments represent a departure from the state of the art. Notably, abrasive articles of embodiments herein may include a bond material including polydimethylsiloxane covalently bonded to a phenoxy. Unexpectedly, abrasive articles of the embodiments herein may have improved performance, such as improved wet strength, which can be expected to improve consistency in wheel grinding performance over a longer time period, and reduced scratch marks on a workpiece. Improved wet retention can make the abrasive article of embodiments herein more suitable for organic wet grinding.

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

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims. Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein. After reading this specification, skilled artisans will appreciate that those aspects and embodiments are only illustrative and do not limit the scope of the present invention. Additionally, those skilled in the art will understand that some embodiments that include analog circuits can be similarly implement using digital circuits, and vice versa.

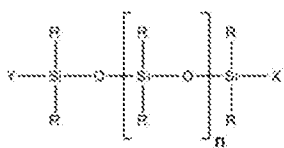
The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The specification

and illustrations are not intended to serve as an exhaustive and comprehensive description of all of the elements and features of apparatus and systems that use the structures or methods described herein. Separate embodiments may also be provided in combination in a single embodiment, and conversely, various features that are, for brevity, described in the context of a
5 single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range. Many other embodiments may be apparent to skilled artisans only after reading this specification. Other embodiments may be used and derived from the disclosure, such that a structural substitution, logical substitution, or another change may be made without departing from the scope of the
10 disclosure. Accordingly, the disclosure is to be regarded as illustrative rather than restrictive. Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the
15 claims.

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

WHAT IS CLAIMED IS:

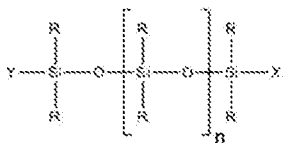
1. A bonded abrasive article, comprising:
a body including abrasive particles contained within a bond material,
wherein the bond material comprises a polymer including a plurality of benzene rings that are covalently bonded to one another and at least one siloxane functional group covalently bonded to the plurality of benzene rings.
2. A bonded abrasive article, comprising:
a body including abrasive particles contained within a bond material,
wherein the bond material has a FTIR signature peak at a wavelength from 1258 cm^{-1} to 1275 cm^{-1} .
3. The bonded abrasive article of claim 1 or 2, wherein the body comprises a wet flexural stress retention of at least 52%.
4. The bonded abrasive article of claim 1 or 2, wherein the bond material comprises siloxane covalently bonded to the plurality of benzene rings, wherein the siloxane is represented by a formula I:



Formula I,

- wherein R includes a methyl or phenyl group, X and Y independently represents hydrogen atoms, a hydrocarbyl group, or an alkoxy group, and n is at least one.
5. The bonded abrasive article of claim 4, wherein the siloxane is covalently bonded to an oxygen atom, wherein the oxygen atom is directly and covalently bonded to one of the plurality of benzene rings.
 6. The bonded abrasive article of claim 4, wherein the siloxane comprises polydimethylsiloxane, and wherein the plurality of benzene rings are covalently bonded to one another by a methylene bridge.
 7. The bonded abrasive article of any one of claims 1 to 6, wherein each of the plurality of benzene rings is covalently bonded to an oxygen atom that is covalently bonded to at least one siloxane functional group.

8. The abrasive article of any one of claims 4 to 7, wherein the bond material comprises a content of the siloxane in a range from at least 1 wt.% to at most 30 wt.% for a total weight of the bond material.
9. The abrasive article of claim 8, wherein the siloxane comprises polymethylsiloxane, wherein the bond material comprises a content of the polymethylsiloxane in a range from at least 1 wt.% to at most 30 wt.% for the total weight of the bond material.
10. The abrasive article of any one of claims 1 to 9, wherein the body comprises a filler including barium sulfate, cryolite, or any combination thereof.
11. A process of forming an abrasive article, comprising:
forming a green body with a mixture comprising abrasive particles and a bond precursor material including a phenolic resin covalently bonded to at least one siloxane functional group.
12. The process of claim 11, wherein the resin has a FTIR signature peak at a wavelength from 1257 cm^{-1} to 1261 cm^{-1} .
13. The process of claim 11 or 12, wherein the phenolic resin is covalently bonded to siloxane represented by a formula I:

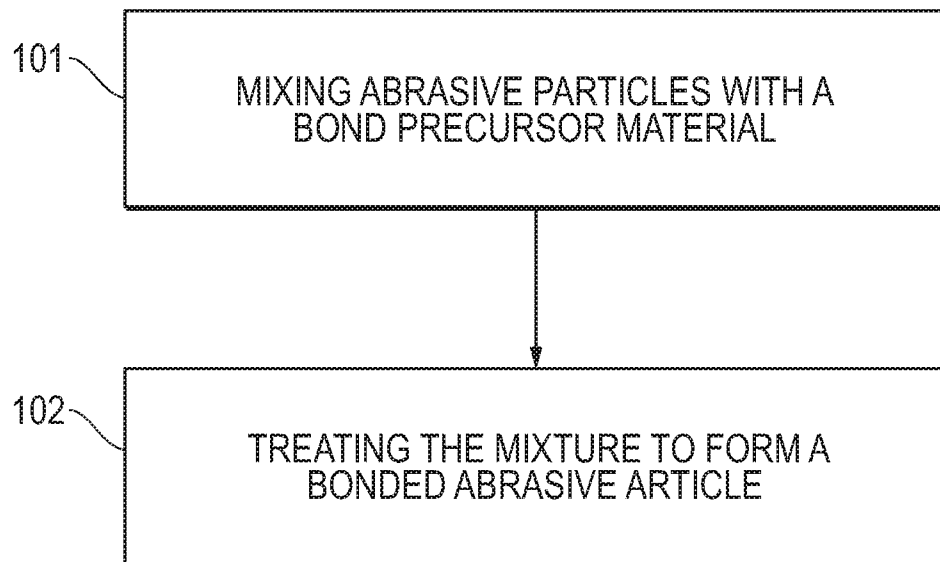


Formula I,

wherein R includes a methyl or phenyl group, X and Y independently represents hydrogen atoms, a hydrocarbyl group, or an alkoxy group, and n is at least one.

14. The process of claim 13, wherein the siloxane comprises polydimethylsiloxane, wherein the polydimethylsiloxane is directly and covalently bonded to an oxygen atom of the phenolic resin.
15. The process of claim 13, wherein the bond precursor material comprises the siloxane in a content from at least 1 wt.% to at most 30 wt.% for a total weight of the bond precursor material.

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*FIG. 1*

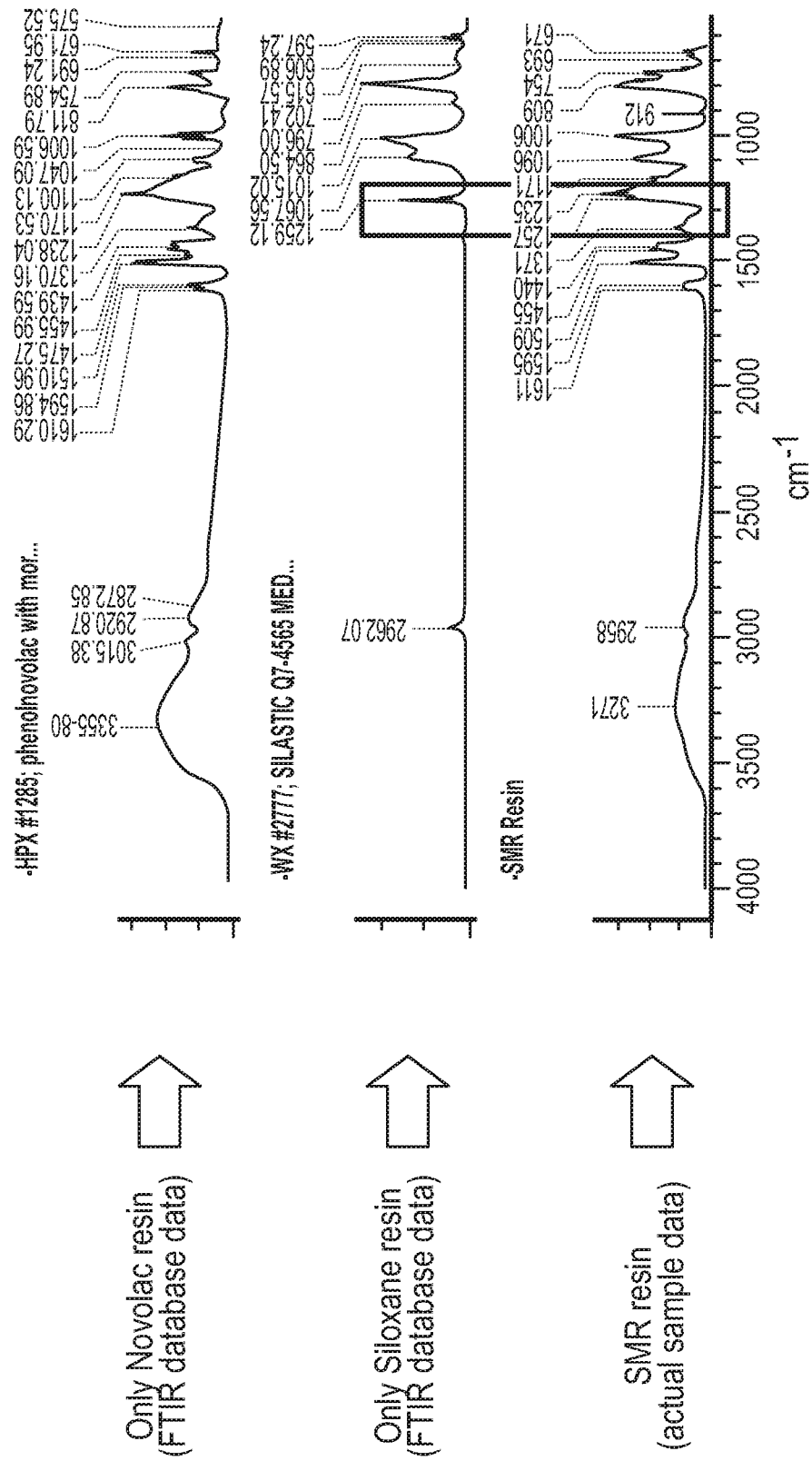


FIG. 2

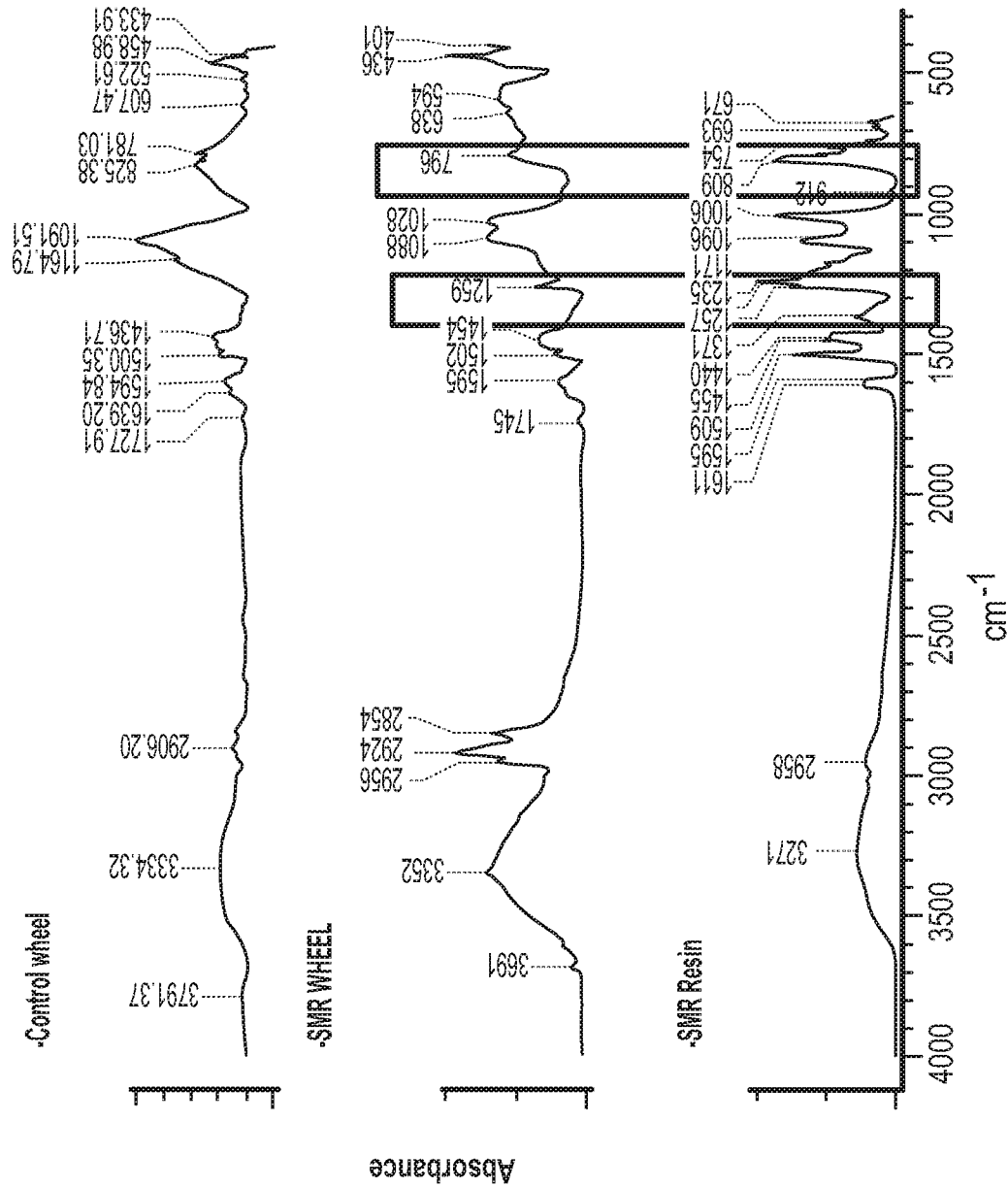


FIG. 3

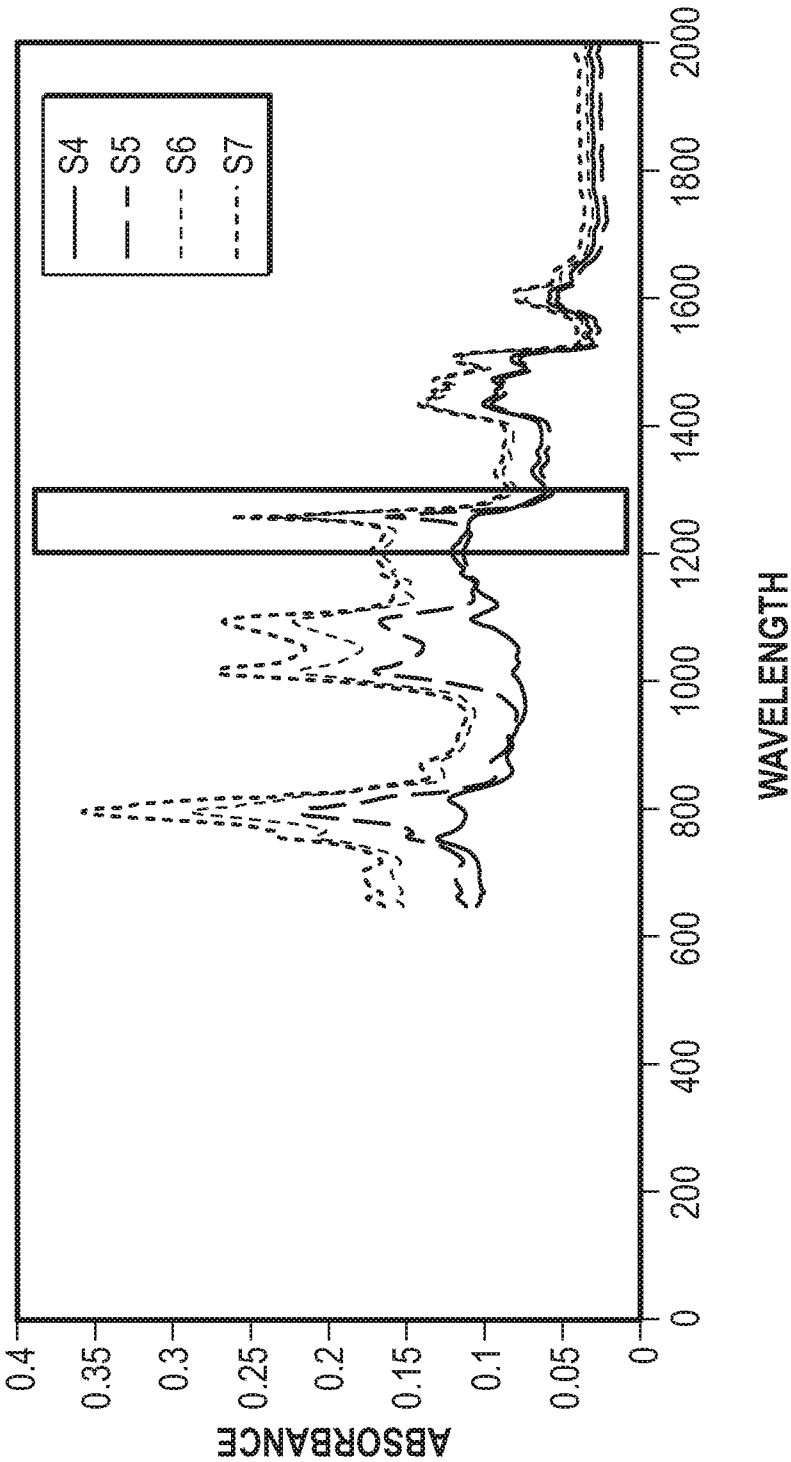


FIG. 4

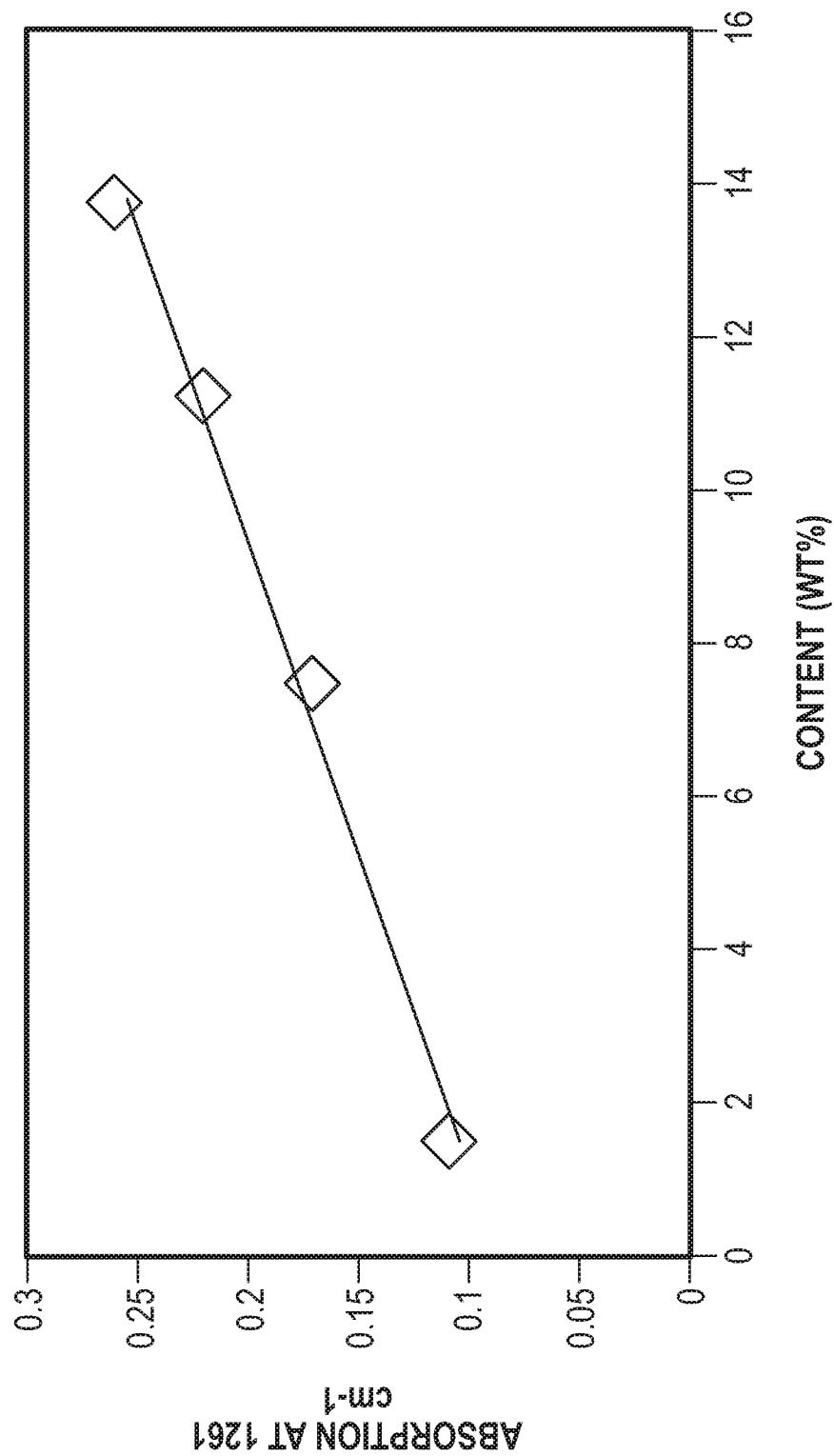


FIG. 5

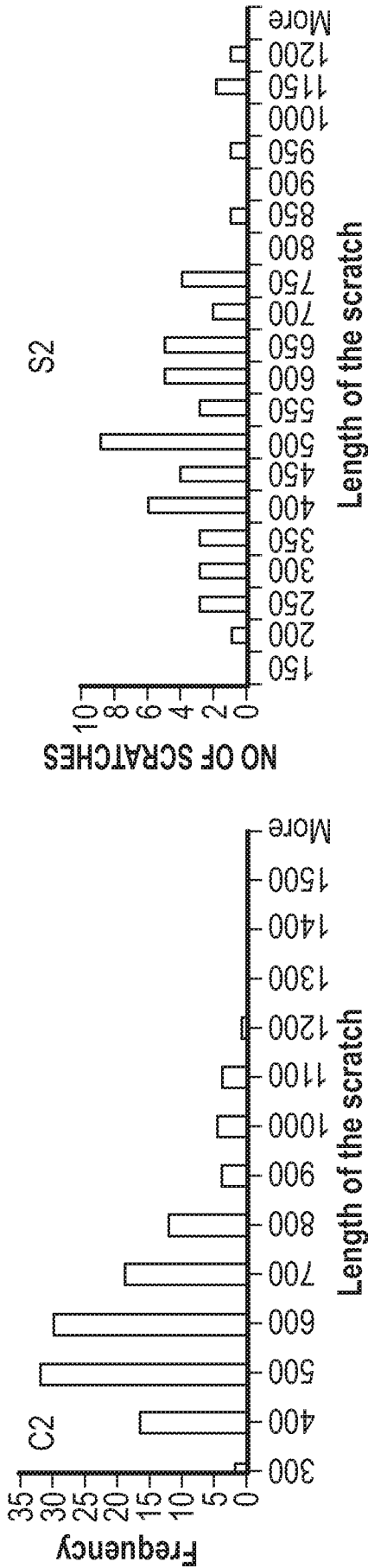


FIG. 6

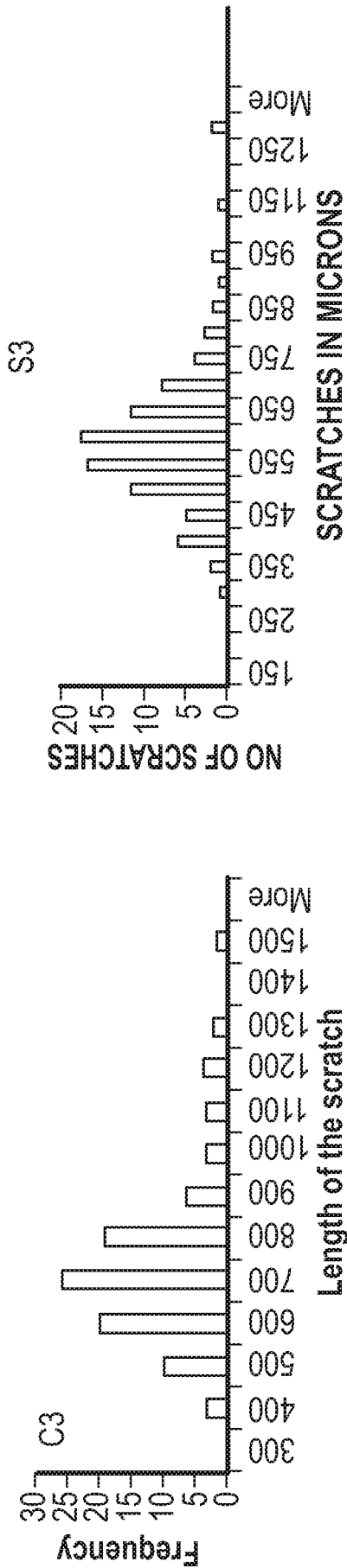


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/067373**A. CLASSIFICATION OF SUBJECT MATTER****C09K 3/14(2006.01)i, C08L 83/04(2006.01)i, B24D 3/28(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C09K 3/14; C08L 83/02; B24D 3/00; B24D 3/28; B24D 11/00; C08L 83/04

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: bonded abrasive article, phenolic resin, siloxane functional group

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0822883 B1 (MINNESOTA MINING AND MANUFACTURING COMPANY) 09 August 2000 See paragraphs [0012]-[0045], [0191]; and claims 1-10.	1-6, 11-15
Y	US 3041156 A (ROWSE, ROBERT A. et al.) 26 June 1962 See columns 1-4; and claim 1.	1-6, 11-15
Y	US 5736619 A (KANE, JOHN F. et al.) 07 April 1998 See columns 1-6; claim 1; and figure 6.	1-6, 11-15
A	US 2003-0192258 A1 (SIMON, MARK W.) 16 October 2003 See paragraphs [0006]-[0010]; and claims 1-29.	1-6, 11-15
A	US 4802896 A (LAW, KAM W. et al.) 07 February 1989 See columns 2-7; and claims 1-11.	1-6, 11-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

15 April 2018 (15.04.2018)

Date of mailing of the international search report

16 April 2018 (16.04.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



Facsimile No. +82-42-481-8578

Authorized officer

KAM, Yoo Lim

Telephone No. +82-42-481-3516



INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US2017/067373**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.: 9
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:
Claim 9 refers to a multiple dependent claim which does not comply with PCT Rule 6.4(a).
3. ☒ Claims Nos.: 7, 8, 10
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:

1. ☐ 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 any 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.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/067373

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0822883 B1	09/08/2000	AU 5174196 A	18/11/1996
		AU 694338 B2	16/07/1998
		BR 9608251 A	29/06/1999
		CA 2217983 A1	31/10/1996
		DE 69609709 T2	14/12/2000
		EP 0822883 A1	19/07/2000
		JP 11-504357 A	20/04/1999
		JP 2008-101211 A	01/05/2008
		JP 4047926 B2	13/02/2008
		JP 4845849 B2	28/12/2011
		MX 9708204 A	31/12/1997
		US 5849052 A	15/12/1998
		WO 96-33841 A1	31/10/1996
US 3041156 A	26/06/1962	DE 1494221 A1	02/01/1969
		FR 1274445 A	27/10/1961
		GB 963334 A	08/07/1964
		SE 300508 B	29/04/1968
US 5736619 A	07/04/1998	CN 1187836 A	15/07/1998
		EP 0821711 A1	02/11/2000
		EP 0821711 B1	13/08/2003
		JP 10-506956 A	07/07/1998
		KR 10-0253975 B1	15/04/2000
		TW 404959 B	11/09/2000
US 2003-0192258 A1	16/10/2003	WO 96-33238 A1	24/10/1996
		AR 038328 A1	12/01/2005
		AT 500899 A2	15/04/2006
		AT 500899 A5	15/02/2007
		AT 500899 B1	15/11/2007
		AU 2002-359803 A1	15/07/2003
		AU 2002-364582 B2	17/11/2005
		AU 2003-251621 A1	25/05/2004
		AU 2003-251621 A8	25/05/2004
		BE 1015339 A5	01/02/2005
		BR 0215570 A	21/12/2004
		CA 2471452 A1	10/07/2003
		CA 2472065 A1	07/08/2003
		CA 2472065 C	17/10/2006
		CH 696192 A5	15/02/2007
		CN 1617787 A	18/05/2005
		CN 1617787 C	05/03/2008
		CZ 20040850 A3	12/01/2005
		DE 10297646 B4	31/01/2008
		DE 10297646 T5	24/02/2005
		DK 200401304 A	30/08/2004
		EP 1468113 A1	20/10/2004
		ES 2244348 A1	01/12/2005

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/067373

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4802896 A	07/02/1989	ES 2244348 B2	01/07/2006
		FI 20041029 A	27/07/2004
		FR 2835256 A1	01/08/2003
		FR 2835256 B1	03/06/2005
		GB 2400373 A	13/10/2004
		GB 2400373 B	31/08/2005
		HU 0402565 A2	29/05/2006
		IT MI20030089 A1	31/07/2003
		JP 2005-515908 A	02/06/2005
		JP 2006-501806 A	19/01/2006
		JP 4199126 B2	17/12/2008
		KR 10-0557697 B1	13/03/2006
		KR 10-2004-0073603 A	19/08/2004
		LU 91090 A1	22/07/2004
		MX PA04007338 A	26/11/2004
		NL 1022519 A1	31/07/2003
		NL 1022519 C2	08/06/2004
		NO 20043597 A	27/08/2004
		NO 326382 B1	24/11/2008
		NZ 533709 A	27/07/2007
		PL 205520 B1	30/04/2010
		PL 369733 A1	02/05/2005
		SE 0401975 L	29/09/2004
		SE 533129 C2	06/07/2010
		TW 200302266 A	01/08/2003
		TW I242597 B	01/11/2005
		US 2004-0191798 A1	30/09/2004
		US 6949129 B2	27/09/2005
		WO 03-056037 A1	10/07/2003
		WO 03-064111 A1	07/08/2003
		WO 2004-039312 A2	13/05/2004
		WO 2004-039312 A3	08/07/2004
		ZA 200405032 B	12/10/2005
		EP 0320172 A2	14/06/1989
		EP 0320172 A3	16/01/1991
		JP 01-205980 A	18/08/1989
		KR 10-1989-0010051 A	05/08/1989