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**(54) ABRASIVE ARTICLE FOR LOWER SPEED GRINDING OPERATIONS**

SCHLEIFMITTEL FÜR SCHLEIFOPERATIONEN BEI NIEDRIGER GESCHWINDIGKEIT

ARTICLE ABRASIF POUR OPÉRATIONS DE MEULAGE À FAIBLE VITESSE

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**Description****TECHNICAL FIELD**

5 [0001] The following is directed to abrasive articles, and particularly bonded abrasive articles suitable for conducting lower speed grinding operations. Such an bonded abrasive article is disclosed for example in US 2008/222967 A1.

**BACKGROUND ART**

10 [0002] Abrasive tools are generally formed to have abrasive grains contained within a bond material for material removal applications. Superabrasive grains (e.g., diamond or cubic boron nitride (CBN)) or seeded (or even unseeded) sintered sol gel alumina abrasive grain, also referred to as microcrystalline alpha-alumina (MCA) abrasive grain, can be employed in such abrasive tools. The bond material can be organic materials, such as a resin, or an inorganic material, such as a glass or vitrified material. In particular, bonded abrasive tools using a vitrified bond material and containing

15 MCA grains or superabrasive grains are commercially useful for grinding.

[0003] Certain bonded abrasive tools, particularly those utilizing a vitrified bond material, require high temperature forming processes, oftentimes on the order of 1100°C or greater, which can have deleterious effects on abrasive grains of MCA. In fact, it has been recognized that at such elevated temperatures necessary to form the abrasive tool, the bond material can react with the abrasive grains, particularly MCA grains, and damage the integrity of the abrasives, reducing

20 the grain sharpness and performance properties. As a result, the industry has migrated toward reducing the formation temperatures necessary to form the bond material in order to curb the high temperature degradation of the abrasive grains during the forming process. The industry continues to demand improved performance of such bonded abrasive articles.

**BRIEF DESCRIPTION OF DRAWINGS**

25 [0004] 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.

30 FIG. 1 includes a diagram of percent porosity, percent abrasive, and percent bond for prior art bonded abrasive bodies. The depicted percentages for porosity, abrasive and bond only partially overlap with the percentages according to the claimed invention as defined by the appended claims.

FIG. 2 includes a photograph illustrating modulus and hardness testing of abrasive grains, bonds and their interfaces.

35 FIG. 3 includes a chart of modulus of elasticity (MOE) for the abrasive, bond and abrasive-to-bond interfaces of two conventional bonded abrasive articles compared to a bonded abrasive article according to an embodiment herein.

FIG. 4 includes a chart of hardness for the abrasive, bond and abrasive-to-bond interfaces of two conventional bonded abrasive articles compared to a bonded abrasive article according to an embodiment herein.

FIG. 5 includes a schematic diagram of an abrasive article illustrating loss of form along both the x-axis and y-axis.

40 FIG. 6 includes a plot of surface finish Ra versus in-feed rate (Z'w) for conventional bonded abrasive articles and a bonded abrasive article according to an embodiment.

FIG. 7 includes a plot of material removal in 5 grinds versus in-feed rate (Z'w) for conventional bonded abrasive articles and a bonded abrasive article according to an embodiment.

FIG. 8 includes a plot of change in x-axis radius versus in-feed rate (Z'w) demonstrating a corner holding factor for conventional bonded abrasive articles and a bonded abrasive article according to an embodiment.

45 FIG. 9 includes a plot of change in y-axis radius versus in-feed rate (Z'w) demonstrating a corner holding factor for conventional bonded abrasive articles and a bonded abrasive article according to an embodiment.

FIG. 10 includes a chart of parts per dress for a conventional bonded abrasive article and a bonded abrasive article according to an embodiment.

50 FIG. 11 includes a chart of cycle time for a conventional bonded abrasive article and a bonded abrasive article according to an embodiment.

[0005] The use of the same reference symbols in different drawings indicates similar or identical items.

**DETAILED DESCRIPTION**

55 [0006] The following is directed to bonded abrasive articles, which may be suitable for grinding and shaping of workpieces. Notably, the bonded abrasive articles of embodiments herein can incorporate abrasive particles within a vitreous bond material. Suitable applications for use of the bonded abrasive articles of the embodiments herein include grinding

operations including for example, centerless grinding, cylindrical grinding, crankshaft grinding, various surface grinding operations, bearing and gear grinding operations, creepfeed grinding, and various toolroom applications.

**[0007]** According to an embodiment, the method of forming a bonded abrasive article of an embodiment can be initiated by forming a mixture of suitable compounds and components to form a bond material. The bond can be formed of compounds of inorganic material, such as oxide compounds. For example, one suitable oxide material can include silicon oxide ( $\text{SiO}_2$ ). In accordance with an embodiment, the bond material can be formed from not greater than about 55 wt% silicon oxide for the total weight of the bond material. In other embodiments, the content of silicon oxide can be less, such as not greater than about 54 wt%, not greater than about 53 wt%, not greater than about 52 wt%, or even not greater than about 51 wt%. Still, in certain embodiments the bond material may be formed from at least about 45 wt%, such as at least about 46 wt%, on the order of at least about 47 wt%, at least about 48 wt%, or even at least about 49 wt% silicon oxide for the total weight of the bond material. It will be appreciated that the amount of silicon oxide can be within a range between any of the minimum and maximum percentages noted above.

**[0008]** The bond material can also incorporate a certain content of aluminum oxide ( $\text{Al}_2\text{O}_3$ ). For example, the bond material can include at least about 12 wt% aluminum oxide for the total weight of the bond material. In other embodiments, the amount of aluminum oxide can be at least about 14 wt%, at least about 15 wt%, or even at least about 16 wt%. In certain instances, the bond material may include an amount of aluminum oxide that is not greater than about 23 wt%, not greater than about 21 wt%, not greater than about 20 wt%, not greater than about 19 wt%, or even not greater than about 18 wt% for the total weight of the bond. It will be appreciated that the amount of aluminum oxide can be within a range between any of the minimum and maximum percentages noted above.

**[0009]** In certain instances, the bond material can be formed from a particular ratio between the amount of silicon oxide as measured in weight percent versus the amount of aluminum oxide as measured in weight percent. For example, the ratio of silica to alumina can be described by dividing the weight percent of silicon oxide by the weight percent of aluminum oxide within the bond material. In accordance with an embodiment, the ratio of silicon oxide to aluminum oxide can be not greater than about 3.2. In other instances, the ratio of silicon oxide to aluminum oxide within the bond material can be not greater than about 3.1, not greater than about 3.0, or even not greater than about 2.9. Still, the bond material can be formed, in certain instances, such that the ratio of weight percent of silicon oxide to the weight percent of aluminum oxide is at least about 2.2, such as at least about 2.3, such as on the order of at least about 2.4, at least about 2.5, at least about 2.6, or even at least about 2.7. It will be appreciated that the total amount of aluminum oxide and silicon oxide can be within a range between any of the minimum and maximum values noted above.

**[0010]** In accordance with the invention the bond material is formed from a certain content of boron oxide ( $\text{B}_2\text{O}_3$ ). According to the invention the bond material incorporates an amount of boron oxide not greater than about 17 wt%, or even not greater than about 16 wt%. Still, the bond material can be formed from at least about 11 wt%, such as at least about 12 wt%, at least about 13 wt%, or even at least about 14 wt% boron oxide for the total weight of the bond material. It will be appreciated that the amount of boron oxide can be within a range between any of the minimum and maximum percentages noted above.

**[0011]** In accordance with one embodiment, the bond material can be formed such that the total content (i.e. sum) of the weight percent of boron oxide and weight percent of silicon oxide within the bond material can be not greater than about 70 wt% for the total weight of the bond material. In other instances, the total content of silicon oxide and boron oxide can be not greater than about 69 wt%, such as not greater than about 68 wt%, not greater than about 67 wt%, or even not greater than about 66 wt%. In accordance with one particular embodiment, the total weight percent content of silicon oxide and boron oxide can be at least about 55 wt%, such as at least about 58 wt%, at least about 60 wt%, at least about 62 wt%, at least about 63 wt%, at least about 64 wt%, or even at least about 65 wt% for the total weight of the bond material. It will be appreciated that the total weight percent of silicon oxide and boron oxide within the bond material can be within a range between any of the minimum and maximum percentages noted above.

**[0012]** Moreover, in particular instances, the amount of silicon oxide can be greater than the amount of boron oxide within the bond material, as measured in weight percent. Notably, the amount of silicon oxide can be at least about 1.5 times greater, at least about 1.7 times greater, at least about 1.8 times greater, at least about 1.9 times greater, at least about 2.0 times greater, or even at least about 2.5 times greater than the amount of boron oxide. Still, in one embodiment, the bond material can include an amount of silicon oxide that is not greater than about 5 times greater, such as not more than about 4 times greater, not more than about 3.8 times greater, or even not more than about 3.5 times greater. It will be appreciated that the difference in the amount of silicon oxide as compared to the amount of boron oxide can be within a range between any of the minimum and maximum values noted above.

**[0013]** In accordance with an embodiment, the bond material can be formed from at least one alkali oxide compound ( $\text{R}_2\text{O}$ ), wherein R represents a metal selected from Group IA elements in the Periodic Table of Elements. For example, the bond material can be formed from an alkaline oxide compound ( $\text{R}_2\text{O}$ ) from the group of compounds including lithium oxide ( $\text{Li}_2\text{O}$ ), sodium oxide ( $\text{Na}_2\text{O}$ ), potassium oxide ( $\text{K}_2\text{O}$ ), and cesium oxide ( $\text{Cs}_2\text{O}$ ), and a combination thereof.

**[0014]** In accordance with an embodiment, the bond material can be formed from a total content of alkali oxide compounds of not greater than about 20 wt% for the total weight of the bond material. For other bonded abrasive articles

according to embodiments herein, the total content of alkali oxide compounds can be not greater than about 19 wt%, not greater than about 18 wt%, not greater than about 17 wt%, not greater than about 16 wt%, or even not greater than about 15 wt%. Still, in one embodiment, the total content of alkali oxide compounds within the bond material can be at least about 10 wt%, such as at least about 12 wt%, at least about 13 wt%, or even at least about 14 wt%. It will be appreciated that the bond material can include a total content of alkali oxide compounds within a range between any of the minimum and maximum percentages noted above.

**[0015]** In accordance with one particular embodiment, the bond material can be formed from not greater than about 3 individual alkali oxide compounds ( $R_2O$ ) as noted above. In fact, certain bond materials may incorporate not greater than about 2 alkali oxide compounds within the bond material.

**[0016]** Furthermore, the bond material can be formed such that the individual content of any of the alkali oxide compounds is not greater than one half of the total content (in weight percent) of alkali oxide compounds within the bond material. Furthermore, in accordance with one particular embodiment, the amount of sodium oxide can be greater than the content (weight percent) of lithium oxide or potassium oxide. In more particular instances, the total content of sodium oxide as measured in weight percent can be greater than the sum of the contents of lithium oxide and potassium oxide as measured in weight percent. Furthermore, in one embodiment, the amount of lithium oxide can be greater than the content of potassium oxide.

**[0017]** In accordance with one embodiment, the total amount of alkali oxide compounds as measured in weight percent forming the bond material can be less than the amount (as measured in weight percent) of boron oxide within the bond material. In fact, in certain instances the total weight percent of alkali oxide compounds as compared to the total weight percent of boron oxide within the bond material can be within a range between about 0.9 to 1.5, such as within a range between about 0.9 and 1.3, or even within a range between about 0.9 and about 1.1.

**[0018]** The bond material can be formed from a certain amount of alkali earth compounds (RO), wherein R represents an element from Group IIA of the Periodic Table of Elements. For example, the bond material can incorporate alkaline earth oxide compounds such as calcium oxide (CaO), magnesium oxide (MgO), barium oxide (BaO), or even strontium oxide (SrO). In accordance with an embodiment, the bond material can contain not greater than about 3.0 wt% alkaline earth oxide compounds for the total weight of the bond material. In still other instances, the bond material may contain less alkaline earth oxide compounds, such as on the order of not greater than about 2.8 wt%, not greater than about 2.2 wt%, not greater than about 2.0 wt%, or not greater than about 1.8 wt%. Still, according to one embodiment, the bond material may contain a content of one or more alkaline earth oxide compounds of at least about 0.5 wt%, such as at least about 0.8 wt%, at least about 1.0 wt%, or even at least about 1.4 wt% for the total weight of the bond material. It will be appreciated that the amount of alkaline earth oxide compounds within the bond material can be within a range between any of the minimum and maximum percentages noted above.

**[0019]** In accordance with an embodiment, the bond material can be formed from not greater than about 3 different alkaline earth oxide compounds. In fact, the bond material may contain not greater than 2 different alkaline earth oxide compounds. In one particular instance, the bond material can be formed from 2 alkaline earth oxide compounds consisting of calcium oxide and magnesium oxide.

**[0020]** In one embodiment, the bond material can include an amount of calcium oxide that is greater than an amount of magnesium oxide. Furthermore, the amount of calcium oxide within the bond material may be greater than the content of any of the other alkaline earth oxide compounds present within the bond material.

**[0021]** The bond material can be formed from a combination of alkali oxide compounds and alkaline earth oxide compounds such that the total content is not greater than about 20 wt% for the total weight of the bond material. In other embodiments, the total content of alkali oxide compounds and alkaline earth oxide compounds within the bond material can be not greater than about 19 wt%, such as not greater than about 18 wt%, or even not greater than about 17 wt%. However, according to the present invention, the total content of alkali oxide compounds and alkaline earth compounds present within the bond material is at least about 14 wt%, at least about 15 wt%, or even at least about 16 wt%. It will be appreciated that the bond material can have a total content of alkali oxide compounds and alkaline earth oxide compounds within a range between any of the minimum and maximum percentages noted above.

**[0022]** In accordance with an embodiment, the bond material can be formed such that the content of alkali oxide compounds present within the bond material is greater than the total content of alkaline earth oxide compounds. In one particular embodiment, the bond material may be formed such that the ratio of total content (in weight percent) of alkali oxide compounds as compared to the total weight percent of alkaline earth oxide compounds ( $R_2O:RO$ ) is within a range between about 5:1 and about 15:1. In other embodiments, the ratio of total weight percent of alkali oxide compounds to total weight percent of alkaline earth oxide compounds present within the bond material can be within a range between about 6:1 and about 14:1, such as within a range between about 7:1 and about 12:1, or even with a range between about 8:1 and about 10:1.

**[0023]** In accordance with an embodiment, the bond material can be formed from not greater than about 3 wt% phosphorous oxide for the total weight of the bond material. In certain other instances, the bond material may contain not greater than about 2.5 wt%, such as not greater than about 2.0 wt%, not greater than about 1.5 wt%, not greater

than about 1.0 wt%, not greater than about 0.8 wt%, not greater than about 0.5 wt%, or even not greater than about 0.2 wt% phosphorous oxide for the total weight of the bond material. In fact, in certain instances, the bond material may be essentially free of phosphorous oxide. Suitable contents of phosphorous oxide can facilitate certain characteristics and grinding performance properties as described herein.

**[0024]** In accordance with one embodiment, the bond material can be formed from not greater than a composition comprising not greater than about 1 wt% of certain oxide compounds, including for example, oxide compounds such as  $\text{MnO}_2$ ,  $\text{ZrSiO}_2$ ,  $\text{CoAl}_2\text{O}_4$ , and  $\text{MgO}$ . In fact, in particular embodiments, the bond material can be essentially free of the above identified oxide compounds.

**[0025]** In addition to the bond materials placed within the mixture, the process of forming the bonded abrasive article can further include the incorporation of a certain type of abrasive particles. In accordance with an embodiment, the abrasive particles can include microcrystalline alumina (MCA). In fact, in certain instances, the abrasive particles can consist essentially of microcrystalline alumina.

**[0026]** The abrasive particles can have an average particle size that is not greater than about 1050 microns. In other embodiments, the average particle size of the abrasive particles can be less, such as on the order of not greater than 800 microns, not greater than about 600 microns, not greater than about 400 microns, not greater than about 250 microns, not greater than about 225 microns, not greater than about 200 microns, not greater than about 175 microns, not greater than about 150 microns, or even not greater than about 100 microns. Still, the average particle size of the abrasive particles can be at least about 1 micron, such as at least about 5 microns, at least about 10 microns, at least about 20 microns, at least about 30 microns, or even at least about 50 microns, at least about 60 microns, at least about 70 microns, or even at least about 80 microns. It will be appreciated that the average particle size of the abrasive particles can be in a range between any of the minimum and maximum values noted above.

**[0027]** In further reference to abrasive particles utilizing microcrystalline alumina, it will be appreciated that microcrystalline alumina can be formed of grains having an average grain size that is sub-micron sized. In fact, the average grain size of a microcrystalline alumina can be not greater than about 1 micron, such as not greater than about 0.5 microns, not greater than about 0.2 microns, not greater than about 0.1 microns, not greater than about 0.08 microns, not greater than about 0.05 microns, or even not greater than about 0.02 microns.

**[0028]** Additionally, formation of the mixture, which includes abrasive particles and bond material can further include the addition of other components, such as fillers, pore formers, and materials suitable for forming the finally-formed bonded abrasive article. Some suitable examples of pore forming materials can include but are not limited to bubble alumina, bubble mullite, hollow spheres including hollow glass spheres, hollow ceramic spheres, or hollow polymer spheres, polymer or plastic materials, organic compounds, fibrous materials including strands and/or fibers of glass, ceramic, or polymers. Other suitable pore forming materials can include naphthalene, PDB, shells, wood, and the like. In still another embodiment, the filler can include one or more inorganic materials, including for example oxides, and particularly may include crystalline or amorphous phases of zirconia, silica, titania, and a combination thereof.

**[0029]** After the mixture is suitably formed, the mixture can be shaped. Suitable shaping processes can include pressing operations and/or molding operations and a combination thereof. For example, in one embodiment, the mixture can be shaped by cold pressing the mixture within a mold to form a green body.

**[0030]** After suitably forming the green body, the green body can be sintered at a particular temperature to facilitate forming an abrasive article having a vitreous phase bond material. Notably, the sintering operation can be conducted at a sintering temperature that is less than about  $1000^\circ\text{C}$ . In particular embodiments, the sintering temperature can be less than about  $980^\circ\text{C}$ , such as less than about  $950^\circ\text{C}$ , and particularly within a range between about  $800^\circ\text{C}$  and  $950^\circ\text{C}$ . It will be appreciated that particularly low sintering temperatures may be utilized with the above-noted bond components such that excessively high temperatures are avoided and thus limiting the degradation of the abrasive particles during the forming process.

**[0031]** According to one particular embodiment, the bonded abrasive body comprises a bond material having a vitreous phase material. In particular instances, the bond material can be a single phase vitreous material.

**[0032]** The finally-formed bonded abrasive body can have a particular content of bond material, abrasive particles, and porosity. Notably, the body of the bonded abrasive article of the present invention has a porosity of at least about 42 vol% for the total volume of the bonded abrasive body. In other embodiments, the amount of porosity can be greater such as at least about 43 vol%, such as at least about 44 vol%, at least about 45 vol%, at least about 46 vol%, at least about 48 vol%, or even at least about 50 vol% for the total volume of the bonded abrasive body. In accordance with the invention the bonded abrasive body has a porosity that is not greater than about 70 vol%, such as not greater than about 65 vol%, not greater than about 62 vol%, not greater than about 60 vol%, not greater than about 56 vol%, not greater than about 52 vol%, or even not greater than about 50 vol%. The bonded abrasive body may include a porosity of about 46% to about 50% of a total volume of the bonded abrasive body, such as a porosity of about 46% to about 48% of a total volume of the bonded abrasive body. It will be appreciated that the bonded abrasive body can have a porosity within a range between any of the minimum and maximum percentages noted above.

**[0033]** In accordance with an embodiment, the bonded abrasive body can have at least about 35 vol% abrasive

particles for the total volume of the bonded abrasive body. In other embodiments, the total content of abrasive particles can be greater, such as at least about 37 vol%, or even at least about 39 vol%. In accordance with one particular embodiment, the bonded abrasive body can be formed such that it has not greater than about 50 vol% abrasive particles, such as not greater than about 48 vol%, or even not greater than about 46 vol% for the total volume of the bonded abrasive body. It will be appreciated that the content of abrasive particles within the bonded abrasive body can be within a range between any of the minimum and maximum percentages noted above.

**[0034]** In particular instances, the bonded abrasive body is formed such that it contains a minor content (vol%) of bond material as compared to the content of porosity and abrasive particles. For example, the bonded abrasive body can have not greater than about 15 vol% bond material for the total volume of the bonded abrasive body. In other instances, the bonded abrasive body can be formed such that it contains not greater than about 14 vol%, not greater than about 13 vol%, or even not greater than about 12 vol% for the total volume of the bonded abrasive body. In one particular instance, the bonded abrasive body can be formed such that it contains at least about 7 vol%, such as at least about 8 vol%, on the order of at least about 9 vol%, or even at least about 10 vol% bond material for the total volume of the bonded abrasive body.

**[0035]** FIG. 1 includes a diagram of phases present within a particular bonded abrasive article according to an embodiment. FIG. 1 includes vol% bond, vol% abrasive particles, and vol% porosity. The shaded region 101 represents a conventional bonded abrasive article suitable for grinding applications, while the shaded region 103 represents the phase contents of a bonded abrasive article according to an embodiment herein.

**[0036]** Notably, the phase content of the conventional bonded abrasive articles (i.e., shaded region 101) is significantly different from the phase content of a bonded abrasive article of an embodiment. Notably, conventional bonded abrasive articles typically have a maximum porosity within a range between approximately 40 vol% and 51 vol%, an abrasive particle content of approximately 42 vol% to 50 vol%, and a bond content of approximately 9 to 20 vol%. Conventional bonded abrasive articles typically have a maximum porosity content of 50 vol% or less because grinding applications require a bonded abrasive body having sufficient strength to deal with the excessive forces encountered during grinding, and highly porous bonded abrasive bodies have not previously been able to withstand said forces.

**[0037]** According to one embodiment not covered by the scope of the present invention, a bonded abrasive article can have a considerably greater porosity than the conventional bonded abrasive articles. For example, one bonded abrasive article of an embodiment can have a porosity content within a range between about 51 vol% and about 58 vol% for the total volume of the bonded abrasive body. Furthermore, as illustrated in FIG. 1, a bonded abrasive article of an embodiment not covered by the scope of the present invention can have an abrasive particle content within a range between about 40 vol% and about 42 vol%, and a particularly low bond content within a range between approximately 2 vol% and about 9 vol% for the total volume of the bonded abrasive article.

**[0038]** Notably, the bonded abrasive bodies of the embodiments herein can have particular characteristics unlike conventional bonded abrasive bodies. In particular, the bonded abrasive articles herein can have a particular content of porosity, abrasive particles, and bond, while demonstrating particular mechanical characteristics making them suitable for particular applications, such as grinding applications. For example, in one embodiment, the bonded abrasive body can have a particular modulus of rupture (MOR), which can correspond to a particular modulus of elasticity (MOE). For example, the bonded abrasive body can have a MOR of at least 45 MPa for a MOE of at least about 40 GPa. In one embodiment, the MOR can be at least about 46 MPa, such as at least about 47 MPa, at least about 48 MPa, at least about 49 MPa, or even at least about 50 MPa for a MOE of 40 GPa. Still, the bonded abrasive body may have an MOR that is not greater than about 70 MPa, such as not greater than about 65 MPa, or not greater than about 60 MPa for a MOE of 40 GPa. It will be appreciated that the MOR can be within a range between any of minimum and maximum values given above.

**[0039]** In another embodiment, for certain bonded abrasive bodies having a MOE of 45 GPa, the MOR can be at least about 45 MPa. In fact, for certain bonded abrasive bodies having a MOE of 45 GPa, the MOR can be at least about 46 MPa, such as at least about 47 MPa, at least about 48 MPa, at least about 49 MPa, or even at least about 50 MPa. Still, the MOR may be not greater than about 70 MPa, not greater than about 65 MPa, or not greater than about 60 MPa for a MOE of 45 GPa. It will be appreciated that the MOR can be within a range between any of minimum and maximum values given above.

**[0040]** MOR can be measured using a standard 3 point bending test on a sample of size 4"x1"x0.5", where the load is applied across the 1"x0.5" plane, generally in accordance with ASTM D790, with the exception of the sample size. The failure load can be recorded and calculated back to MOR using standard equations. MOE can be calculated through measurement of natural frequency of the composites using a GrindoSonic instrument or similar equipment, as per standard practices in the abrasive grinding wheel industry.

**[0041]** In one embodiment, the bonded abrasive body can have a strength ratio, which is a measure of the MOR divided by the MOE. In particular instances, the strength ratio (MOR/MOE) of a particular bonded abrasive body can be at least about 0.8. In other instances, the strength ratio can be at least about 0.9, such as at least about 1.0, at least about 1.05, at least about 1.10. Still, the strength ratio may be not greater than about 3.00, such as not greater than

about 2.50, not greater than about 2.00, not greater than about 1.70, not greater than about 1.50, not greater than about 1.40, or not greater than about 1.30. It will be appreciated that the strength ratio of the bonded abrasive bodies can be within a range between any of the minimum and maximum values noted above.

**[0042]** In accordance with an embodiment, the bonded abrasive body can be suitable for use in particular grinding operations. For example, it has been discovered that the bonded abrasive bodies of embodiments herein are suitable in grinding operations. In fact, the bonded abrasive bodies can be utilized without damaging the workpiece and providing suitable or improved grinding performance.

**[0043]** Reference herein to the grinding capabilities of the bonded abrasive body can relate to grinding operations such as centerless grinding, cylindrical grinding, crankshaft grinding, various surface grinding operations, bearing and gear grinding operations, creepfeed grinding, and various toolroom grinding processes. Moreover, suitable workpieces for the grinding operations can include inorganic or organic materials. In particular instances, the workpiece can include a metal, metal alloy, plastic, or natural material. In one embodiment, the workpiece can include a ferrous metal, non-ferrous metal, metal alloy, metal superalloy, and a combination thereof. In another embodiment, the workpiece can include an organic material, including for example, a polymer material. In still other instances, the workpiece may be a natural material, including for example, wood.

**[0044]** Some versions of the wheel sizes of these abrasive articles may range from greater than about 11.43 cm (4.5 inches) to about 137.16 cm (54 inches) in diameter. Typical stock removal amounts may range from about 0.000254 cm (0.0001 inches) to about 1.27 cm (0.500 inches), depending on the application.

**[0045]** In particular instances, it has been noted that the bonded abrasive body is capable of grinding workpieces at particularly high removal rates. For example, in one embodiment, the bonded abrasive body can conduct a grinding operation at a material removal rate of at least about 0.4 in<sup>3</sup>/min/in (258 mm<sup>3</sup>/min/mm). In other embodiments, the material removal rate can be at least about 0.45 in<sup>3</sup>/min/in (290 mm<sup>3</sup>/min/mm), such as at least about 0.5 in<sup>3</sup>/min/in (322 mm<sup>3</sup>/min/mm), at least about 0.55 in<sup>3</sup>/min/in (354 mm<sup>3</sup>/min/mm), or even at least about 0.6 in<sup>3</sup>/min/in (387 mm<sup>3</sup>/min/mm). Still, the material removal rate for certain bonded abrasive bodies may be not greater than about 1.5 in<sup>3</sup>/min/in (967 mm<sup>3</sup>/min/mm), such as not greater than about 1.2 in<sup>3</sup>/min/in (774 mm<sup>3</sup>/min/mm), not greater than about 1.0 in<sup>3</sup>/min/in (645 mm<sup>3</sup>/min/mm), or even not greater than about 0.9 in<sup>3</sup>/min/in (580 mm<sup>3</sup>/min/mm). It will be appreciated that the bonded abrasive bodies of the present application can grind a workpiece at the material removal rates within a range between any of the minimum and maximum values noted above.

**[0046]** During certain grinding operations, it has been noted that the bonded abrasive bodies of the present application can grind at a particular depth of cut (DOC). For example, the depth of cut achieved by the bonded abrasive body can be at least about 0.003 inches (0.0762 millimeters). In other instances, the bonded abrasive body is capable of achieving a depth of cut during grinding operations of at least about 0.004 inches (0.102 millimeters), such as at least about 0.0045 inches (0.114 millimeters), at least about 0.005 inches (0.127 millimeters), or even at least about 0.006 inches (0.152 millimeters). It will be appreciated that the depth of cut for grinding operations utilizing the bonded abrasive bodies herein may not be greater than about 0.01 inches (0.254 millimeters), or not greater than about 0.009 inches (0.229 millimeters). It will be appreciated that the depth of cut can be within a range between any of the minimum and maximum values noted above.

**[0047]** In other embodiments, it has been noted that the bonded abrasive body can grind a workpiece at a maximum power that does not exceed about 10 Hp (7.5 kW), while the grinding parameters noted above are utilized. In other embodiments, the maximum power during grinding operations may be not greater than about 9 Hp (6.8 kW), such as not greater than about 8 Hp (6.0 kW), or even not greater than about 7.5 Hp (5.6 kW).

**[0048]** In accordance with another embodiment, during grinding operations, it has been noted that the bonded abrasive articles of the embodiments herein have superior corner holding ability, particularly as compared to conventional bonded abrasive articles. In fact, the bonded abrasive body can have a corner holding factor of not greater than about 0.1778 cm (0.07 inches) at an in-feed rate (Z'w) of not greater than 4.572 cm/min (1.8 inches/min), which corresponds to 0.006477 cm/sec,rad (0.00255 inches/sec,rad). Notably, as used herein, an in-feed rate (Z'w) of 2.54 cm/min (1.0 inches/min) corresponds to 0.003607 cm/sec,rad (0.00142 inches/sec,rad), and an in-feed rate (Z'w) of 3.556 cm/min (1.4 inches/min) correspond to 0.005029 cm/sec,rad (0.00198 inches/sec,rad). It will be appreciated that the corner holding factor is a measure of a change in radius after conducting 5 grinds on a workpiece of 4330V, which is a NiCrMoV hardened and tempered high strength steel alloy at a particular in-feed rate (Z'w). In certain other embodiments, the bonded abrasive article demonstrates a corner holding factor that is not greater than about 0.1524 cm (0.06 inches), such as not greater than about 0.127 cm (0.05 inches), not greater than about 0.1016 cm (0.04 inches), for an in-feed rate (Z'w) of not greater than about 4.572 cm/min (1.80 inches/min).

**[0049]** In one embodiment, an abrasive article may include a bonded abrasive body having abrasive particles contained within a bond material. The bonded abrasive body may include an abrasive particle-to-bond material interfacial modulus of elasticity (MOE) of at least about 225 GPa. The bonded abrasive body may be configured to grind a workpiece comprising metal at a speed of less than about 60 m/s.

**[0050]** For example, the abrasive particle-to-bond material interfacial MOE may be at least about 250 GPa, such as

at least about 275 GPa, or even at least about 300 GPa. Alternatively, the abrasive particle-to-bond material interfacial MOE may be no greater than about 350 GPa, such as no greater than about 325 GPa, or even no greater than about 320 GPa.

**[0051]** In another embodiment, an abrasive article may include a bonded abrasive body having abrasive particles contained within a bond material. The bonded abrasive body may include an abrasive particle-to-bond material interfacial hardness of at least about 13 GPa. The bonded abrasive body may be configured to grind a workpiece comprising metal at a speed of less than about 60 m/s. In other examples, the abrasive particle-to-bond material interfacial hardness may be at least about 14 GPa, or even at least about 15 GPa. Alternatively, the abrasive particle-to-bond material interfacial hardness may be no greater than about 20 GPa, such as no greater than about 18 GPa, or even no greater than about 16 GPa.

**[0052]** In still another example, the bonded abrasive body may include a surface finish of not greater than about 3.175  $\mu\text{m}$  (125 micro-inch).

**[0053]** The bonded abrasive body may perform at an in-feed rate ( $Z'w$ ) of at least about 2.54 cm/min (1.0 inches/min). For example,  $Z'w$  may be not greater than about 3.556 cm/min (1.4 inches/min), not greater than about 4.572 cm/min (1.8 inches/min), not greater than about 5.08 cm/min (2.0 inches/min), or even 5.588 cm/min (2.2 inches/min).

**[0054]** In one version, the bonded abrasive body may include a material removal rate of at least about 3.851  $\text{cm}^3/\text{min}$  (0.235  $\text{in}^3/\text{min}$ ).

**[0055]** Embodiments of an abrasive article may include a bonded abrasive body having abrasive particles contained within a bond material. The bonded abrasive body may include a grinding factor defined as a change of x-axis radius over a change in in-feed rate. The grinding factor may be not greater than about 0.040 min. The bonded abrasive body may be configured to grind a workpiece comprising metal at a speed of less than about 60 m/s. The grinding factor may be not greater than about 0.035 min, such as a grinding factor not greater than about 0.030 min, or even a grinding factor not greater than about 0.028 min.

**[0056]** In a particular embodiment, the bonded abrasive body may include an x-axis corner holding factor of not greater than about 0.2032 cm (0.080 inches). For example, the x-axis corner holding factor may be not greater than about 0.1778 cm (0.070 inches), such as not greater than about 0.1524 cm (0.060 inches), not greater than about 0.127 cm (0.050 inches), or even not greater than about 0.1067 cm (0.042 inches).

**[0057]** The corner holding factor may be expressed as a percentage change in the radius of a wheel. For example, for a wheel having a 17.78 cm diameter (7-inch diameter), i.e., a 8.89 cm radius (3.5-inch radius), an x-axis corner holding factor of 0.2032 cm (0.080 inches) represents a change of:  $1 - (3.5 - 0.08)/3.5 = 2.3\%$  change in the x-axis radius of the wheel. For the x-axis corner holding factors of 0.1778, 0.1524, 0.127 and 0.1067 cm (0.07, 0.06, 0.05 and 0.042 inches), the change in x-axis radius of the wheel is 2%, 1.7%, 1.4% and 1.2%, respectively. Accordingly, the bonded abrasive body may have a change in x-axis radius of no greater than 3%. For example, the bonded abrasive body may have a change in x-axis radius of no greater than 2.5%, such as no greater than about 2%, no greater than about 1.7%, no greater than about 1.5%, or even no greater than about 1.3%.

**[0058]** Other embodiments of the bonded abrasive body may include a grinding factor defined as a change of y-axis radius over a change in in-feed rate. The grinding factor may be not greater than about 0.018 min. Other examples of the grinding factor may be not greater than about 0.016 min, such as a grinding factor not greater than about 0.014 min, a grinding factor not greater than about 0.012 min, or even a grinding factor not greater than about 0.010 min.

**[0059]** In a particular embodiment, the bonded abrasive body may include a y-axis corner holding factor of not greater than about 0.08382 cm (0.033 inches), such as not greater than about 0.0762 cm (0.030 inches), not greater than about 0.0635 cm (0.025 inches), or even not greater than about 0.06096 cm (0.024 inches).

**[0060]** The corner holding factor may be expressed as a percentage change in the radius of a wheel. For example, for a wheel having a 17.78 cm diameter (7-inch diameter), i.e., a 8.89 cm radius (3.5-inch radius), a y-axis corner holding factor of 0.08382 cm (0.033 inches) represents a change of:  $1 - (3.5 - 0.033)/3.5 = 0.94\%$  change in the y-axis radius of the wheel. For the y-axis corner holding factors of 0.0762, 0.0635 and 0.06096 cm (0.03, 0.025 and 0.024 inches), the change in x-axis radius of the wheel is 0.86%, 0.71% and 0.69%, respectively.

**[0061]** Accordingly, the bonded abrasive body may have a change in y-axis radius of no greater than about 1%. For example, the bonded abrasive body may have a change in x-axis radius of no greater than about 0.9%, such as no greater than about 0.8%, or even no greater than about 0.7%.

**[0062]** Other versions of the abrasive article may include the body requiring at least about 3% fewer dressings than a conventional OD abrasive grinding wheel, such as at least about 4%, at least about 5%, or even at least about 6% fewer dressings than a conventional OD abrasive grinding wheel.

**[0063]** In another example, the body may require at least about 5% less cycle time than a conventional OD abrasive grinding wheel. For example, the body may require at least about 10% less cycle time, such as at least about 15%, or even at least about 18% less cycle time than a conventional OD abrasive grinding wheel.

**[0064]** Embodiments of the abrasive article may have a bonded abrasive body that can be configured to grind a workpiece comprising metal at a speed of less than about 55 m/s. For example, the speed may be less than about 50



m/s, such as less than about 45 m/s, or even less than about 40 m/s. In still other versions, the speed may be at least about 35 m/s, such as at least about 40 m/s, at least about 45 m/s, or even at least about 50 m/s.

**[0065]** The abrasive article may have a body including a wheel having an outer diameter in a range of about 60.96 cm (24 inches) to about 76.2 cm (30 inches), such as about 45.72 cm (18 inches) to about 76.2 cm (30 inches), about 25.4 cm (10 inches) to about 91.44 cm (36 inches), or even about 12.7 cm (5 inches) to about 137.16 cm (54 inches).

**[0066]** Other embodiments of the abrasive article may include a bond material that includes a single phase vitreous material. Some versions of the bonded abrasive body may include a porosity of at least about 42 vol% of the total volume of the bonded abrasive body, such as a porosity of not greater than about 70 vol%.

**[0067]** The bonded abrasive body may include at least about 35 vol% abrasive particles of the total volume of the bonded abrasive body. In another example, the bonded abrasive body may include not greater than about 15 vol% bond material of the total volume of the bonded abrasive body.

**[0068]** Examples of the bond material may be formed from not greater than about 20 wt% boron oxide ( $B_2O_3$ ) for the total weight of the bond material. In another version, the bond material may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent aluminum oxide ( $Al_2O_3$ ), ( $SiO_2:Al_2O_3$ ), of not greater than about 3.2. The bond material may be formed from not greater than about 3.0 wt% phosphorous oxide ( $P_2O_5$ ). Alternatively, the bond material may be essentially free of phosphorous oxide ( $P_2O_5$ ).

**[0069]** Other embodiments of the bond material may be formed from an alkaline earth oxide compound (RO). For example, a total amount of alkaline earth oxide compound (RO) present in the bond material may be not greater than about 3.0 wt%. The bond material may be formed from not greater than about 3 different alkaline earth oxide compounds (RO) selected from the group of calcium oxide (CaO), magnesium oxide (MgO), barium oxide (BaO), strontium oxide (SrO). The bond material also may include an alkali oxide compound ( $R_2O$ ) selected from the group of compounds consisting of lithium oxide ( $Li_2O$ ), sodium oxide ( $Na_2O$ ), potassium oxide ( $K_2O$ ), and cesium oxide ( $Cs_2O$ ) and a combination thereof. The bond material may be formed from a total amount of alkali oxide compound ( $R_2O$ ) not greater than about 20 wt%. Alternatively, the bond material may include not greater than about 3 alkali oxide compounds ( $R_2O$ ). In another example, a content (wt%) of any alkali oxide compound present within the bond material may be not greater than half of a total content (wt%) of alkali oxides.

**[0070]** In still other embodiments, the bond material is formed from not greater than about 55 wt% silicon oxide ( $SiO_2$ ). The bond material may be formed from at least about 12 wt% aluminum oxide ( $Al_2O_3$ ). The bond material also may be formed from at least one alkali oxide compound ( $R_2O$ ) and at least one alkaline earth oxide compound (RO), wherein the total content of the alkali oxide compound and the alkaline earth oxide compound is not greater than about 20 wt%.

**[0071]** Some examples of the bond may be formed from boron oxide ( $B_2O_3$ ) and silicon oxide ( $SiO_2$ ), wherein the total content of boron oxide and silicon oxide may be not greater than about 70 wt%. The content of silicon oxide ( $SiO_2$ ) may be greater than the content of boron oxide.

**[0072]** In a particular version, the bond may be formed from a composition comprising not greater than about 1 wt% of oxide compounds selected from the group consisting of  $MnO_2$ ,  $ZrSiO_2$ ,  $CoAl_2O_4$ , and MgO. The bond may be formed from a composition essentially free of oxide compounds selected from the group consisting of  $MnO_2$ ,  $ZrSiO_2$ ,  $CoAl_2O_4$ , and MgO. In addition, the bonded abrasive body may be sintered at a temperature of not greater than about 1000°C.

**[0073]** Embodiments of the bond material may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent aluminum oxide ( $Al_2O_3$ ) ( $SiO_2:Al_2O_3$ ) of about 2.4 to about 3.5. The bond material may include a trace amount (<1%) of each of  $Fe_2O_3$ ,  $TiO_2$  and Mg, and combinations thereof. The bond material may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent CaO ( $SiO_2:CaO$ ) of about 32 to about 52. The bond material also may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $Li_2O$  ( $SiO_2:Li_2O$ ) of about 9.6 to about 26. In another example, the bond material may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $Na_2O$  ( $SiO_2:Na_2O$ ) of about 4.8 to about 10.4. The bond material may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $K_2O$  ( $SiO_2:K_2O$ ) of about 9.6 to about 26. The bond material also may include a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $B_2O_3$  ( $SiO_2:B_2O_3$ ) of about 2.8 to about 5.2.

**[0074]** Embodiments of the bond material may include a ratio of weight percent aluminum oxide ( $Al_2O_3$ ) to weight percent CaO ( $Al_2O_3:CaO$ ) of about 10 to about 20. The bond material may include a ratio of weight percent aluminum oxide ( $Al_2O_3$ ) to weight percent  $Li_2O$  ( $Al_2O_3:Li_2O$ ) of about 3 to about 10. The bond material also may include a ratio of weight percent aluminum oxide ( $Al_2O_3$ ) to weight percent  $Na_2O$  ( $Al_2O_3:Na_2O$ ) of about 1.5 to about 4. An example of the bond material may include a ratio of weight percent aluminum oxide ( $Al_2O_3$ ) to weight percent  $K_2O$  ( $Al_2O_3:K_2O$ ) of about 3 to about 10. The bond material also may include a ratio of weight percent aluminum oxide ( $Al_2O_3$ ) to weight percent  $B_2O_3$  ( $Al_2O_3:B_2O_3$ ) of about 0.9 to about 2.

**[0075]** In another example, the bond material may include a ratio of weight percent CaO to weight percent  $Li_2O$  ( $CaO:Li_2O$ ) of about 0.2 to about 0.75. The bond material may include a ratio of weight percent CaO to weight percent  $Na_2O$  ( $CaO:Na_2O$ ) of about 0.1 to about 0.3. The bond material also may include a ratio of weight percent CaO to weight percent  $K_2O$  ( $CaO:K_2O$ ) of about 0.2 to about 0.75. In addition, the bond material may include a ratio of weight percent CaO to weight percent  $B_2O_3$  ( $CaO:B_2O_3$ ) of about 0.16 to about 0.15.

**[0076]** Other embodiments of the bond material can include a ratio of weight percent  $\text{Li}_2\text{O}$  to weight percent  $\text{Na}_2\text{O}$  ( $\text{Li}_2\text{O}:\text{Na}_2\text{O}$ ) of about 0.2 to about 1. The bond material can include a ratio of weight percent  $\text{Li}_2\text{O}$  to weight percent  $\text{K}_2\text{O}$  ( $\text{Li}_2\text{O}:\text{K}_2\text{O}$ ) of about 0.4 to about 2.5. The bond material also can include a ratio of weight percent  $\text{Li}_2\text{O}$  to weight percent  $\text{B}_2\text{O}_3$  ( $\text{Li}_2\text{O}:\text{B}_2\text{O}_3$ ) of about 0.12 to about 0.5.

**[0077]** A particular embodiment of the bond material may include a ratio of weight percent  $\text{Na}_2\text{O}$  to weight percent  $\text{K}_2\text{O}$  ( $\text{Na}_2\text{O}:\text{K}_2\text{O}$ ) of about 1 to about 5. The bond material also may include a ratio of weight percent  $\text{Na}_2\text{O}$  to weight percent  $\text{B}_2\text{O}_3$  ( $\text{Na}_2\text{O}:\text{B}_2\text{O}_3$ ) of about 0.3 to about 1. In addition, the bond material can include a ratio of weight percent  $\text{K}_2\text{O}$  to weight percent  $\text{B}_2\text{O}_3$  ( $\text{K}_2\text{O}:\text{B}_2\text{O}_3$ ) of about 0.12 to about 0.5.

**[0078]** Other examples of the abrasive article may include a bonded abrasive body having abrasive particles contained within a bond material formed from not greater than about 20 wt% boron oxide ( $\text{B}_2\text{O}_3$ ), having a ratio of weight percent silica ( $\text{SiO}_2$ ): weight percent alumina ( $\text{Al}_2\text{O}_3$ ) of not greater than about 3.2 (by weight percent) and not greater than about 3.0 wt% phosphorous oxide ( $\text{P}_2\text{O}_5$ ), wherein the bonded abrasive body has a porosity of at least about 42 vol% of the total volume of the bonded abrasive body. The bonded abrasive body may be capable of grinding a workpiece comprising metal at a speed of less than about 60 m/s.

**[0079]** Embodiments of a method of grinding an abrasive article may include forming a bonded abrasive body with abrasive particles contained within a bond material, such that the bonded abrasive body comprises an abrasive particle-to-bond material interfacial modulus of elasticity (MOE) of at least about 225 GPa. The method may include grinding a workpiece comprising metal with the bonded abrasive body at a speed of less than about 60 m/s.

**[0080]** Another embodiment of a method of grinding an abrasive article may include forming a bonded abrasive body having abrasive particles contained within a bond material, such that the bonded abrasive body comprises an abrasive particle-to-bond material interfacial hardness of at least about 13 GPa. The method may include grinding a workpiece comprising metal with the bonded abrasive body at a speed of less than about 60 m/s.

**[0081]** Still another embodiment of the method of grinding an abrasive article can include forming a bonded abrasive body having abrasive particles contained within a bond material, such that the bonded abrasive body comprises a grinding factor defined as a change of x-axis radius over a change in in-feed rate, and the grinding factor is not greater than about 0.040 min for an in-feed rate ( $Z'w$ ) of at least about 2.54 cm/min (1.0 inches/min). The method may include grinding a workpiece comprising metal with the bonded abrasive body at a speed of less than about 60 m/s.

**[0082]** A method of grinding an abrasive article also can include forming a bonded abrasive body having abrasive particles contained within a bond material, such that the bonded abrasive body comprises a grinding factor defined as a change of y-axis radius over a change in in-feed rate, and the grinding factor is not greater than about 0.018 min for an in-feed rate ( $Z'w$ ) of at least about 2.54 cm/min (1.0 inches/min). The method may include grinding a workpiece comprising metal with the bonded abrasive body at a speed of less than about 60 m/s.

**[0083]** Still another method of grinding an abrasive article can include forming a bonded abrasive body having abrasive particles contained within a bond material formed from not greater than about 20 wt% boron oxide ( $\text{B}_2\text{O}_3$ ), having a ratio of weight percent silica ( $\text{SiO}_2$ ): weight percent alumina ( $\text{Al}_2\text{O}_3$ ) of not greater than about 3.2 (by weight percent) and not greater than about 3.0 wt% phosphorous oxide ( $\text{P}_2\text{O}_5$ ), wherein the bonded abrasive body has a porosity of at least about 42 vol% of the total volume of the bonded abrasive body. The method may include grinding a workpiece comprising metal with the bonded abrasive body at a speed of less than about 60 m/s.

## EXAMPLES

### Example 1

**[0084]** The life or performance of a wheel in OD grinding applications may be dependent on the number of grinds it can sustain, or the number of parts that can be ground before the wheel loses its form or corner holding ability, which will also impact the part quality. The life of the wheel also may relate to the dressing frequency needed to generate a fresh surface for the subsequent grinding operation. The form holding or corner holding ability of the wheel also may be related to the ability of the bond to hold the grain and retain its goodness for the efficient grinding operation. In this example, abrasive wheels having 38A fused alumina abrasive particles with different bonds were tested. The test device was an MTS Nanoindenter XP, using a Berkovich-type indenter tip. For each sample, indents were attempted at 20 locations along a double line (see FIG. 2) extending from an abrasive particle, across the grain boundary to the bond region, and then into the next abrasive particle. Spacing between the indents in the row was 10 microns, and the rows themselves were separated by a distance of 10 microns. Indentation proceeded to a depth of 1 micron.

**[0085]** FIGS. 3 and 4 depict a comparison of the modulus of elasticity (MOE) and hardness, respectively, for three different bonds. Plots 1301, 1302, and 1303 represent the MOE of the abrasive, bond, and abrasive-to-bond interface, respectively, of a sample of the bonded abrasive articles formed according to an embodiment herein. This sample had a range of bond content of approximately 7 vol% to approximately 12 vol% of a total volume of the bonded abrasive body. In addition, this sample had a range of porosity of approximately 46 vol% to approximately 50 vol% of a total

volume of the bonded abrasive body.

**[0086]** In FIG. 3, a first conventional sample CS1 produced MOE values 1305, 1306, and 1307 for its abrasive, bond, and abrasive-to-bond interface, respectively. Sample CS1 is a bonded abrasive article commercially available as VS product from Saint Gobain Corporation. A second conventional sample CS2 is a bonded abrasive article commercially available as VH product from Saint Gobain Corporation. Sample CS2 produced MOE values 1310, 1311, and 1312 for its abrasive, bond, and abrasive-to-bond interface, respectively.

**[0087]** As shown in FIG. 3, the interface MOE 1303 of the embodiment significantly outperformed the interface MOEs 1307 and 1312 of conventional samples CS1 and CS2, respectively. Such results show a remarkable improvement in the MOE of the abrasive-to-bond interface of bonded abrasive articles formed according to the embodiments herein over state-of-the-art conventional bonded abrasive articles.

**[0088]** In FIG. 4, plots 1401, 1402, and 1403 represent the hardness of the abrasive, bond, and abrasive-to-bond interface, respectively, of the sample of the bonded abrasive articles formed according to the embodiment of FIG. 3. The first conventional sample CS1 produced hardness values 1405, 1406, and 1407 for its abrasive, bond, and abrasive-to-bond interface, respectively. Sample CS1 is the same as that disclosed above for FIG. 3. Similarly, the second conventional sample CS2 produced hardness values 1410, 1411, and 1412 for its abrasive, bond, and abrasive-to-bond interface, respectively. Sample CS2 is the same as that disclosed above for FIG. 3.

**[0089]** As shown in FIG. 4, the interface hardness 1403 of the embodiment significantly outperformed the interface hardnesses 1407 and 1412 of conventional samples CS1 and CS2, respectively. Such results show a remarkable improvement in the hardness of the abrasive-to-bond interface of bonded abrasive articles formed according to the embodiments herein over state-of-the-art conventional bonded abrasive articles.

**[0090]** Thus, the new bond has higher modulus and hardness. This is particularly significant for the weaker parts in the abrasive wheels (the bond and interface). The improvement in modulus and hardness of interface can help to strengthen the interface and shows that it has better connectivity with the abrasives. These designs are helpful for improving life of abrasive wheels under aggressive grinding conditions.

## Example 2

**[0091]** For this corner holding application and test, four samples of 7-inch wheels were prepared. The four samples included three different conventional bonds and one bond in accordance with an embodiment herein. All four samples included 38A fused alundum grain, and each included a bond content of about 7 vol% to about 12 vol%, as well as a porosity of about 46% to about 50% of a total volume of the bonded abrasive body. The conventional samples used the same VS and VH bonds used in Example 1. Table 1 contains more details regarding the test conditions used in Example 2.

Table 1

Material:	4330V	Work Speed	232
Lot #:	287	[rpm]:	
Machine:	Bryant	Sparkout [s]:	0.2
Coolant:	E 812	Hardness:	28-32 RC
Wheel Speed [sfpm]:	9915	Part Width [in]:	0.35
		Grind Width [in]:	0.10
Dress Type:	Rotary	Full Scale [V]:	10.0
Dress Comp [in]:	015" Radius 015" Face	Full Scale [V]:	10.0
Dress Lead [in/sec]:	0.0020	Ft (lbs/V):	30.00
Dresser Speed [rpm]:	3787	Power [hp/V]:	2.14
		Apprx. Whl OD [in]:	7.000
		Apprx. Wrk OD [in]:	3.745

**[0092]** The four samples were tested on a Bryant grinder in a corner holding configuration. The wheel speed was 50.36 m/s. The test material was 9.5123 cm (3.745-inch) OD 4330V steel ( $R_c = 28-32$ ). The test material speed was 1.15 m/sec. The grinding mode was external plunge with a 0.254 cm (0.100-inch) width of grind. Each wheel was dressed with the help of a reverse plated diamond roll. The infeed rates were adjusted to give target material removal rates (Z'W)

of 645, 903 and 1161 mm<sup>3</sup>/min/mm (1.0, 1.4 and 1.8 inch<sup>3</sup>/min/inch). Five consecutive radial grinds without dressing were performed on each of the test wheels at the target feed rates. Surface finish and waviness were obtained from the work material after the last grind. For the corner radius and radial wear measurements, after each grind, the test wheel was used to grind a Formica blank that records the wheel profile. The measurements were obtained from the blank.

**[0093]** FIG. 6 includes plots of surface finish Ra versus in-feed rate (Z'w) for the three conventional bonded abrasive articles 1600, 1601 and 1602 and the embodiment of the bonded abrasive article 1605. The embodiment of the bonded abrasive body 1605 comprises a surface finish of not greater than about 2.159 μm (85 micro-inch) at an in-feed rate (Z'w) of 3.556 cm/min (1.4 inches/min). In contrast, the articles 1600, 1601 and 1602 all exhibited surface finishes of at least about 3.175 μm (125 micro-inch) at an in-feed rate (Z'w) of 3.556 cm/min (1.4 inches/min).

**[0094]** FIG. 7 includes plots of material removal in 5 grinds versus in-feed rate (Z'w) for the same three conventional bonded abrasive articles 1700, 1701 and 1702 and the embodiment of the bonded abrasive article 1705. The bonded abrasive body 1705 included a material removal rate of at least about 3.949 cm<sup>3</sup>/min (0.241 in<sup>3</sup>/min) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min). In contrast, the conventional articles 1700, 1701 and 1702 all exhibited material removal rates of no greater than about 3.851 cm<sup>3</sup>/min (0.235 in<sup>3</sup>/min) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min).

**[0095]** A schematic diagram of the corner wear or change in radius measurements is shown in FIG. 5. Dimension 1500 represents the original dimension (i.e., the axial width of 2.2225 cm (0.875 inches)) of a sample along the x-axis, while dimension 1501 represents the post-grinding dimension of the sample along the x-axis. Similarly, dimension 1502 represents the original dimension (i.e., the diameter of 17.78 cm (7 inches)) of a sample along the y-axis, while dimension 1503 represents the post-grinding dimension of the sample along the y-axis.

**[0096]** FIG. 8 includes plots of change in x-axis radius versus in-feed rate (Z'w) demonstrating a corner holding factor for the same three conventional bonded abrasive articles 1800, 1801 and 1802 and the embodiment of the bonded abrasive article 1805. The embodiment of the bonded abrasive body 1805 included an x-axis corner holding factor of about 0.1067 cm (0.042 inches) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min). In contrast, the conventional articles 1800, 1801 and 1802 all exhibited x-axis corner holding factors of at least about 0.2032 cm (0.080 inches) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min).

**[0097]** In addition, the bonded abrasive body 1805 included a grinding factor defined as a change of x-axis radius over a change in in-feed rate. The grinding factors are essentially the average slopes of the lines in FIG. 8. For example, for body 1805, the grinding factor has a numerator of 0.042 in - 0.019 in = 0.023 in. The denominator is 1.80 in/min - 1.00 in/min = 0.80 in/min. 0.023 in/0.80 in/min = grinding factor of about 0.029 min. In contrast, articles 1800, 1801 and 1802 had a grinding factor of at least about 0.050 min.

**[0098]** Similarly, FIG. 9 includes plots of change in y-axis radius versus in-feed rate (Z'w) demonstrating a corner holding factor for the same three conventional bonded abrasive articles 1900, 1901 and 1902 and the embodiment of the bonded abrasive article 1905. The body 1905 exhibited a y-axis corner holding factor of about 0.06096 cm (0.024 inches) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min). The articles 1900, 1901 and 1902 had y-axis corner holding factors of at least about 0.08382 cm (0.033 inches) at an in-feed rate (Z'w) of 4.572 cm/min (1.8 inches/min).

**[0099]** Grinding factors also were calculated based on FIG. 9. For example, for body 1905, the grinding factor has a numerator of 0.024 in - 0.016 in = 0.008 in. The denominator is 1.80 in/min - 1.00 in/min = 0.80 in/min. 0.008 in/0.80 in/min = grinding factor of about 0.01 min. In contrast, articles 1900, 1901 and 1902 had a grinding factor of at least about 0.0188 min.

**[0100]** Thus, the change in the corner radius along both the x-axis and the y-axis shows that a product with a bond in accordance with an embodiment herein shows the least amount of corner wear at all material removal rates compared to products made with conventional bond systems.

### Example 3

**[0101]** In this example, an embodiment including a combination of sol-gel and fused alumina abrasive was formed with the bond described above for the previous examples. This sample was tested in a centerless plunge application to finish form against a conventional product having a combination of sol-gel and fused alumina abrasive with the conventional bond VH used previously for the other examples. The grinding wheels had 40.64 cm (16-inch) diameters and the material ground was mild steel (1014). The objective was to improve productivity by increasing parts per dress. The wheel speed was 57.45 m/sec and part speed was 1.15 m/sec.

**[0102]** Table 2 contains more details regarding the test conditions used in Example 3.

Table 2

Test Conditions		
	Units (if any)	
Machine		Cincinnati Viking Centerless series
Coolant Type		Castrol 9951
Dresser RPM		4200
Radial Depth/Pass	cm (in)	0.00254 (0.001)
Comps (passes) / Dress		1
Total Dress Depth	cm (in)	0.00254 (0.001)
Wheel speed	rpm	2700
Infeed Rates (R1)	cm/min (in/min)	2.79908 (1.102)
Infeed Rates (R2)	cm/min (in/min)	1.89992 (0.748)
Infeed Rates (Finish)	cm/min (in/min)	0.8001 (0.315)

**[0103]** FIG. 10 includes a chart of parts per dress for a conventional bonded abrasive article 2000 and the embodiment of the bonded abrasive article 2005. Article 2005 showed significant improvement in parts per dress (about 7% improved) with a good surface finish or form, compared to article 2000.

**[0104]** Another advantage observed was that the in-feed rates could be significantly increased for the new wheel that helped in reduction of cycle time. Lower cycle times have better efficiency in grinding operations. The same samples described for FIG. 10 were tested for cycle time and the results are displayed in FIG. 11. FIG. 11 is a chart of cycle time for the conventional bonded abrasive article 2100 and the embodiment of the bonded abrasive article 2105. Article 2105 showed a significant (approximately 18%) improvement over article 2100.

**[0105]** The foregoing embodiments are directed to abrasive products, and particularly bonded abrasive products, which represent a departure from the state-of-the-art. The bonded abrasive products of the embodiments herein utilize a combination of features that facilitate improved grinding performance. As described in the present application, the bonded abrasive bodies of the embodiments herein utilize a particular amount and type of abrasive particles, particular amount and type of bond material, and have a particular amount of porosity. In addition to the discovery that such products could be formed effectively, despite being outside of the known realm of conventional abrasive products in terms of their grade and structure, it was also discovered that such products demonstrated improved grinding performance. Notably, it was discovered that the bonded abrasives of the present embodiments are capable of operating at lower speeds during grinding operations despite having significantly higher porosity than conventional grinding wheels. In fact, quite surprisingly, the bonded abrasive bodies of the embodiments herein demonstrated a capability of operating at wheel speeds of less than about 60 m/s, while also demonstrating improved material removal rates, improved corner holding ability, and suitable surface finish as compared to state-of-the-art grinding wheels.

## Claims

### 1. An abrasive article comprising:

a bonded abrasive body having microcrystalline alumina abrasive particles contained within a bond material, wherein the bonded abrasive body comprises an abrasive particle-to-bond material interfacial modulus of elasticity (MOE) of at least 225 GPa; and

wherein the bonded abrasive body comprises a bond content of at least 7 vol% and not greater than 12 vol% for a total volume of the bonded abrasive body, a porosity content of at least 42 vol% and not greater than 70 vol% for the total volume of the bonded abrasive body, and an abrasive particle content of at least 35 vol% and not greater than 50 vol% for the total volume of the bonded abrasive body; and

wherein the bond material comprises a total content of a combination of alkali oxide compounds ( $R_2O$ ) and alkaline earth oxide compounds (RO) of at least 14 wt% for a total weight of the bond material, and a boron oxide ( $B_2O_3$ ) content of at least 11 wt% and not greater than 17 wt% of the total weight of the bond material.

### 2. The abrasive article of claim 1, wherein the bonded abrasive body is configured to grind a workpiece comprising

metal at a speed of less than about 60 m/s.

3. The abrasive article of claim 1, wherein the bonded abrasive body comprises an abrasive particle-to-bond material interfacial hardness of at least 13 GPa and not greater than 20 GPa.
4. The abrasive article of claim 1, wherein the bond material is formed from at least one alkali oxide compound ( $R_2O$ ) and at least one alkaline earth oxide compound (RO), wherein a total content of the alkali oxide compound and the alkaline earth oxide compound is not greater than 20 wt% for a total weight of the bond material.
5. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $Li_2O$  ( $SiO_2:Li_2O$ ) of 9.6 to 26.
6. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $Na_2O$  ( $SiO_2:Na_2O$ ) of 4.8 to 10.4.
7. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $K_2O$  ( $SiO_2:K_2O$ ) of 9.6 to 26.
8. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent silicon oxide ( $SiO_2$ ) to weight percent  $B_2O_3$  ( $SiO_2:B_2O_3$ ) of 2.8 to 5.2.
9. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent  $Li_2O$  to weight percent  $Na_2O$  ( $Li_2O:Na_2O$ ) of 0.2 to 1.
10. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent  $Li_2O$  to weight percent  $K_2O$  ( $Li_2O:K_2O$ ) of 0.4 to 2.5.
11. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent  $Na_2O$  to weight percent  $K_2O$  ( $Na_2O:K_2O$ ) of 1 to 5.
12. The abrasive article of claim 1, wherein the bonded abrasive body comprises a grinding factor defined as a change of axial width over a change in in-feed rate, and the grinding factor is not greater than 0.040 min for an in-feed rate ( $Z'w$ ) of at least about 2.54 cm/min (1.0 inches/min).
13. The abrasive article of claim 1, wherein the bonded abrasive body comprises a grinding factor defined as a change of diameter over a change in in-feed rate, and the grinding factor is not greater than 0.018 min for an in-feed rate ( $Z'w$ ) of at least about 2.54 cm/min (1.0 inches/min).
14. The abrasive article of claim 1, wherein the bond material comprises a ratio of weight percent silica to weight percent alumina, ( $SiO_2:Al_2O_3$ ), of not greater than 3.2 and not greater than 3.0 wt% phosphorous oxide ( $P_2O_5$ ).

## Patentansprüche

### 1. Schleifmittel, umfassend:

einen gebundenen Schleifkörper, aufweisend mikrokristalline Aluminiumoxid-Schleifpartikeln, die in einem Bindematerial enthalten sind, wobei der gebundene Schleifkörper einen Grenzflächen-Elastizitätsmodul (modulus of elasticity, MOE) von Schleifpartikel zu Bindematerial von mindestens 225 GPa umfasst; und wobei der gebundene Schleifkörper bezogen auf ein Gesamtvolumen des gebunden Schleifkörpern einen Bindemittelbehalt von mindestens 7 Vol.-% und nicht mehr als 12 Vol.-%, bezogen auf das Gesamtvolumen des gebunden Schleifkörpern einen Porositätsgehalt von mindestens 42 Vol.-% und nicht mehr als 70 Vol.-% und bezogen auf das Gesamtvolumen des gebunden Schleifkörpern einen Schleifpartikelgehalt von mindestens 35 Vol.-% und nicht mehr als 50 Vol.-% umfasst; und wobei das Bindematerial bezogen auf ein Gesamtgewicht des Bindematerials einen Gesamtgehalt einer Kombination aus Alkalioxidverbindungen ( $R_2O$ ) und Erdalkalioxidverbindungen (RO) von mindestens 14 Gew.-% und einen Boroxidgehalt ( $B_2O_3$ ) von mindestens 11 Gew.-% und nicht mehr als 17 Gew.-% des Gesamtgewichts des Bindematerials umfasst.

2. Schleifmittel nach Anspruch 1, wobei der gebundene Schleifkörper konfiguriert ist, um ein Metall umfassendes Werkstück mit einer Geschwindigkeit von weniger als ca. 60 m/s zu schleifen.
3. Schleifmittel nach Anspruch 1, wobei der gebundene Schleifkörper eine Härte der Schleifpartikel-Bindematerial-Grenzflächenhärte von mindestens 13 GPa und nicht mehr als 20 GPa umfasst.
4. Schleifmittel nach Anspruch 1, wobei das Bindematerial aus mindestens einer Alkalioxidoxidverbindung ( $R_2O$ ) und mindestens einer Erdalkalioxidoxidverbindung (RO) gebildet ist, wobei ein Gesamtgehalt der Alkalioxidoxidverbindung und der Erdalkalioxidverbindung bezogen auf ein Gesamtgewicht des Bindematerials nicht mehr als 20 Gew.-% beträgt.
5. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent Siliziumdioxid ( $SiO_2$ ) zu Gewichtsprozent  $Li_2O$  ( $SiO_2:Li_2O$ ) von 9,6 bis 26 umfasst.
6. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent Siliziumdioxid ( $SiO_2$ ) zu Gewichtsprozent  $Na_2O$  ( $SiO_2:Na_2O$ ) von 4,8 bis 10,4 umfasst.
7. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent Siliziumdioxid ( $SiO_2$ ) zu Gewichtsprozent  $K_2O$  ( $SiO_2:K_2O$ ) von 9,6 bis 26 umfasst.
8. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent Siliziumdioxid ( $SiO_2$ ) zu Gewichtsprozent  $B_2O_3$  ( $SiO_2:B_2O_3$ ) von 2,8 bis 5,2 umfasst.
9. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent  $Li_2O$  zu Gewichtsprozent  $Na_2O$  ( $Li_2O:Na_2O$ ) von 0,2 bis 1 umfasst.
10. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent  $Li_2O$  zu Gewichtsprozent  $K_2O$  ( $Li_2O:K_2O$ ) von 0,4 bis 2,5 umfasst.
11. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent  $Na_2O$  zu Gewichtsprozent  $K_2O$  ( $Na_2O:K_2O$ ) von 1 bis 5 umfasst.
12. Schleifmittel nach Anspruch 1, wobei der gebundene Schleifkörper einen Schleiffaktor umfasst, der als Änderung der axialen Breite über eine Änderung der Zustellgeschwindigkeit definiert ist und der Schleiffaktor bei einer Zustellgeschwindigkeit ( $Z'w$ ) von mindestens ca. 2,54 cm/min (1,0 Zoll/min) nicht größer als 0,040 min ist.
13. Schleifmittel nach Anspruch 1, wobei der gebundene Schleifkörper einen Schleiffaktor umfasst, der als Änderung des Durchmessers über eine Änderung der Zustellgeschwindigkeit definiert ist und der Schleiffaktor bei einer Zustellgeschwindigkeit ( $Z'w$ ) von mindestens ca. 2,54 cm/min (1,0 Zoll/min) nicht größer als 0,018 min ist.
14. Schleifmittel nach Anspruch 1, wobei das Bindematerial ein Verhältnis von Gewichtsprozent Siliziumdioxid zu Gewichtsprozent Aluminiumoxid ( $SiO_2:Al_2O_3$ ) von nicht mehr als 3,2 und nicht mehr als 3,0 Gew.-% Phosphoroxid ( $P_2O_5$ ) umfasst.

## Revendications

### 1. Article abrasif comprenant :

un corps abrasif lié ayant des particules abrasives d'alumine microcristalline contenues dans un matériau de liaison, dans lequel le corps abrasif lié comprend un module d'élasticité interfaciale (MOE) de particules abrasives à matériau de liaison d'au moins 225 GPa ; et  
 dans lequel le corps abrasif lié comprend une teneur en liant d'au moins 7 % en volume et non supérieure à 12 % en volume pour un volume total du corps abrasif lié, une teneur en porosité d'au moins 42 % en volume et non supérieure à 70 % en volume pour le volume total du corps abrasif lié et une teneur en particules abrasives d'au moins 35 % en volume et non supérieure à 50 % en volume pour le volume total du corps abrasif lié ; et  
 dans lequel le matériau de liaison comprend une teneur totale en une combinaison de composés d'oxyde alcalin ( $R_2O$ ) et de composés d'oxyde alcalino-terreux (RO) d'au moins 14 % en poids pour un poids total de matériau

de liaison et une teneur en un oxyde de bore ( $B_2O_3$ ) d'au moins 11 % en poids et non supérieure à 17 % en poids du poids total du matériau de liaison.

2. Article abrasif selon la revendication 1, dans lequel le corps abrasif lié est configuré pour meuler une pièce à usiner comprenant du métal à une vitesse inférieure à environ 60 m/s.
3. Article abrasif selon la revendication 1, dans lequel le corps abrasif lié comprend une dureté interfaciale de particules abrasives à matériau de liaison d'au moins 13 GPa et non supérieure à 20 GPa.
4. Article abrasif selon la revendication 1, dans lequel le matériau de liaison est formé d'au moins un composé d'oxyde alcalin ( $R_2O$ ) et d'au moins un composé d'oxyde alcalino-terreux (RO), dans lequel une teneur totale du composé d'oxyde alcalin et du composé d'oxyde alcalino-terreux ne dépasse pas 20 % en poids pour un poids total du matériau de liaison.
5. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids d'oxyde de silicium ( $SiO_2$ ) et le pourcentage en poids de  $Li_2O$  ( $SiO_2:Li_2O$ ) de 9,6 à 26.
6. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids d'oxyde de silicium ( $SiO_2$ ) et le pourcentage en poids de  $Na_2O$  ( $SiO_2:Na_2O$ ) de 4,8 à 10,4.
7. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids d'oxyde de silicium ( $SiO_2$ ) et le pourcentage en poids de  $K_2O$  ( $SiO_2:K_2O$ ) de 9,6 à 26.
8. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport du pourcentage en poids d'oxyde de silicium ( $SiO_2$ ) au pourcentage en poids de  $B_2O_3$  ( $SiO_2:B_2O_3$ ) de 2,8 à 5,2.
9. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids de  $Li_2O$  au pourcentage en poids de  $Na_2O$  ( $Li_2O:Na_2O$ ) de 0,2 à 1.
10. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids de  $Li_2O$  et le pourcentage en poids de  $K_2O$  ( $Li_2O:K_2O$ ) de 0,4 à 2,5.
11. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport entre le pourcentage en poids de  $Na_2O$  et le pourcentage en poids de  $K_2O$  ( $Na_2O:K_2O$ ) de 1 à 5.
12. Article abrasif selon la revendication 1, dans lequel le corps abrasif lié comprend un facteur de meulage défini comme un changement de largeur axiale sur un changement de vitesse d'alimentation et le facteur de meulage n'est pas supérieur à 0,040 min pour une vitesse d'alimentation ( $Z'w$ ) d'au moins environ 2,54 cm/min (1,0 pouce/min).
13. Article abrasif selon la revendication 1, dans lequel le corps abrasif lié comprend un facteur de meulage défini comme un changement de diamètre sur un changement de vitesse d'alimentation et le facteur de meulage n'est pas supérieur à 0,018 min pour une vitesse d'alimentation ( $Z'w$ ) d'au moins environ 2,54 cm/min (1,0 pouce/min).
14. Article abrasif selon la revendication 1, dans lequel le matériau de liaison comprend un rapport du pourcentage en poids de silice au pourcentage en poids d'alumine, ( $SiO_2:Al_2O_3$ ), non supérieur à 3,2 et pas plus de 3,0% en poids d'oxyde de phosphore ( $P_2O_5$ ).



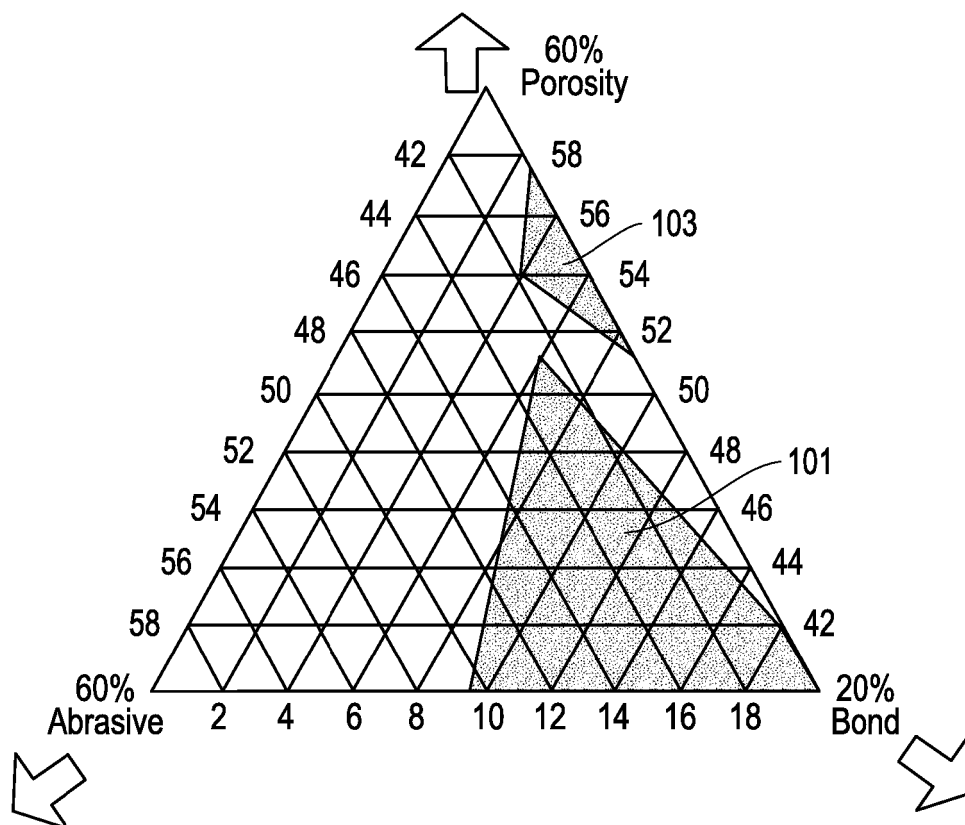
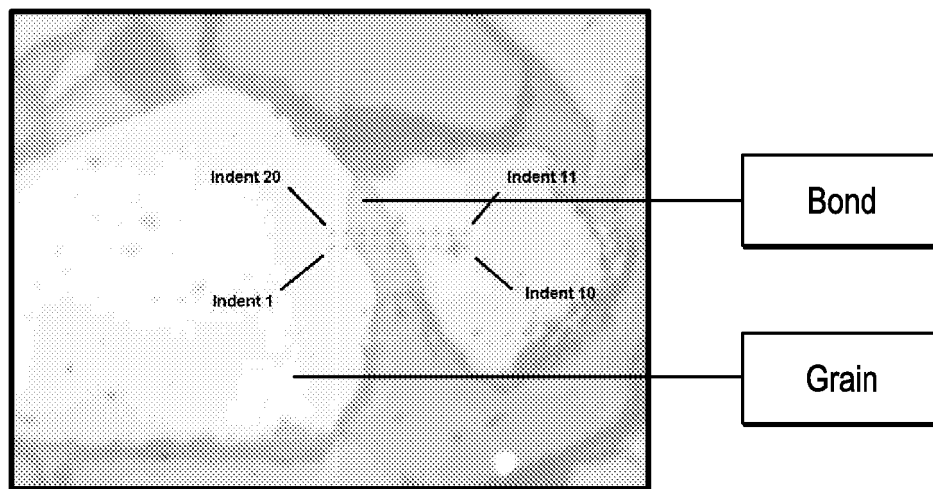
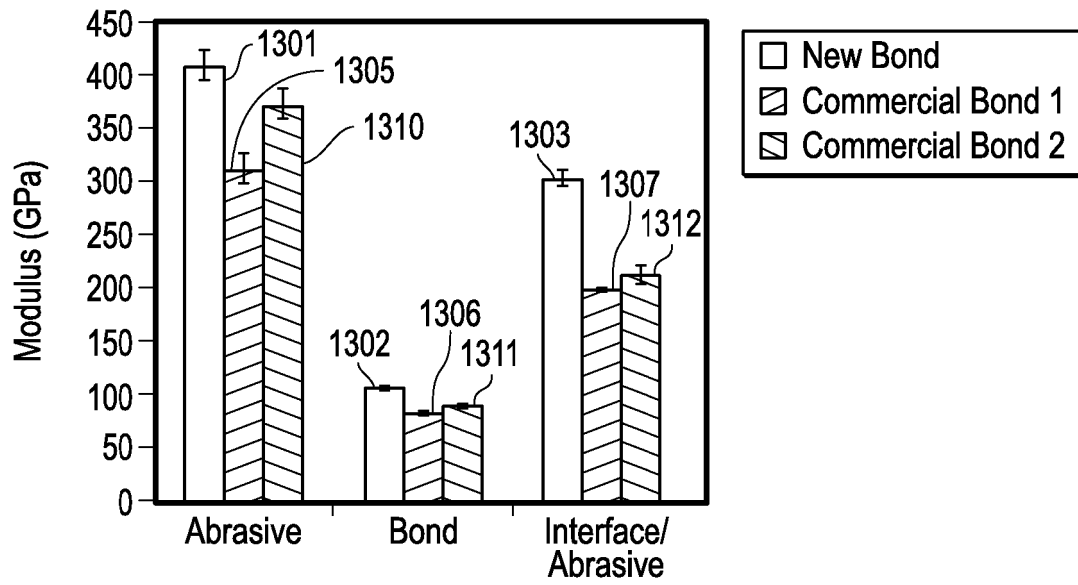


FIG. 1

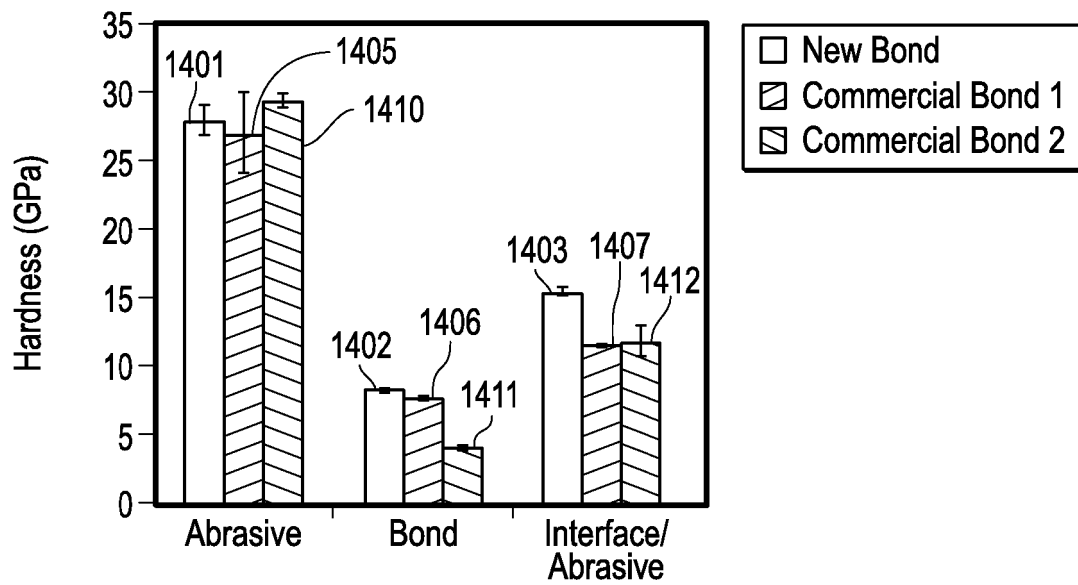


*FIG. 2*



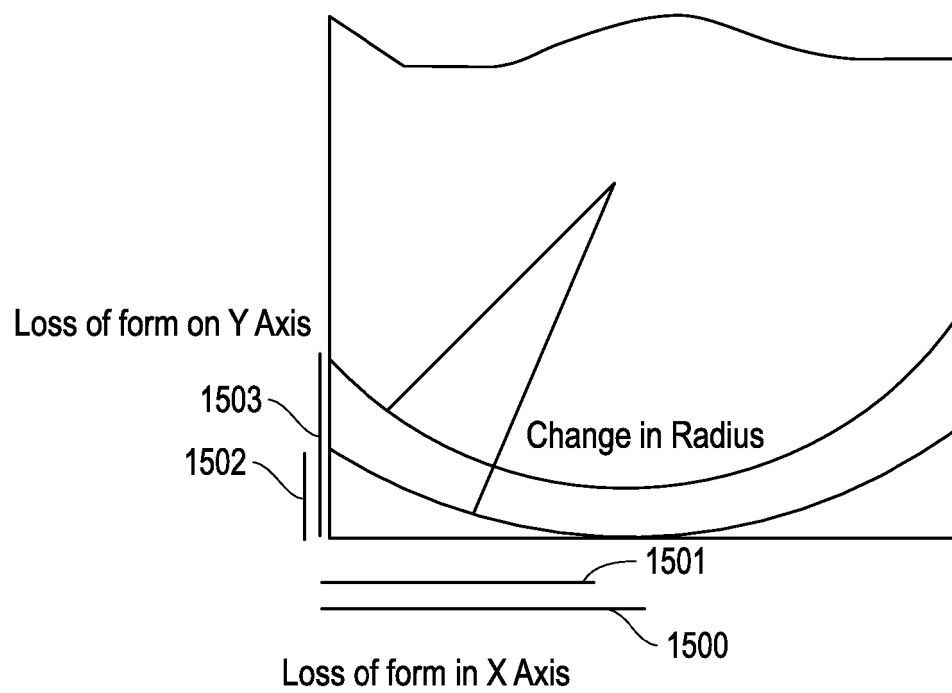
Modulus Measurements from nano-indentation

FIG. 3



Hardness Measurements from nano-indentation

FIG. 4



*FIG. 5*

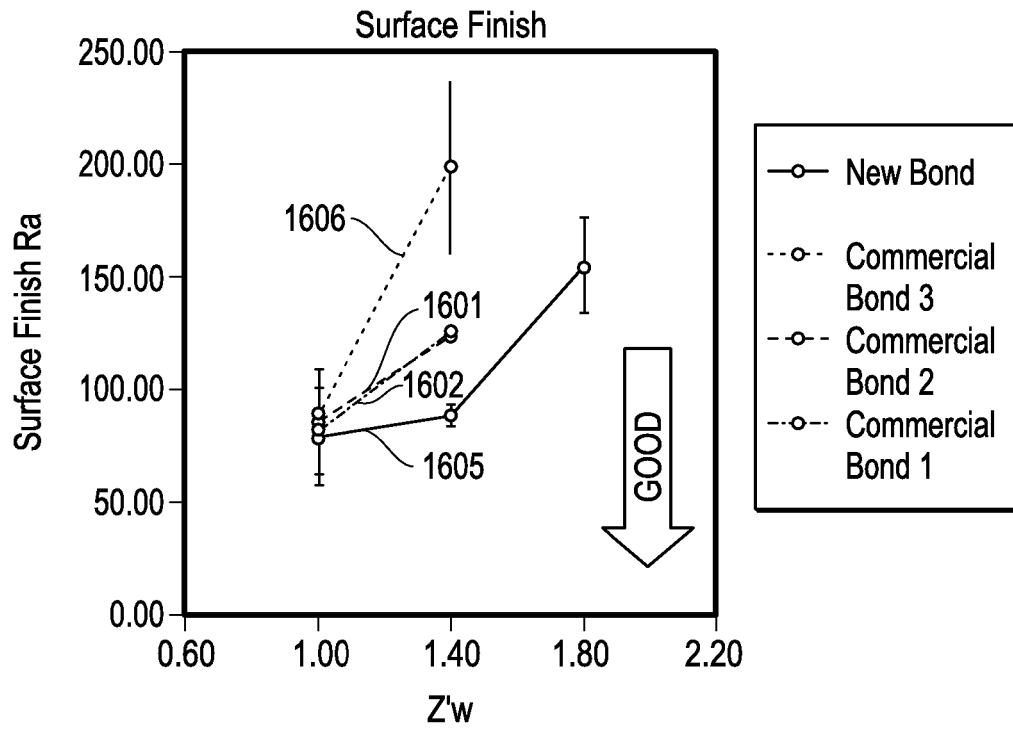


FIG. 6

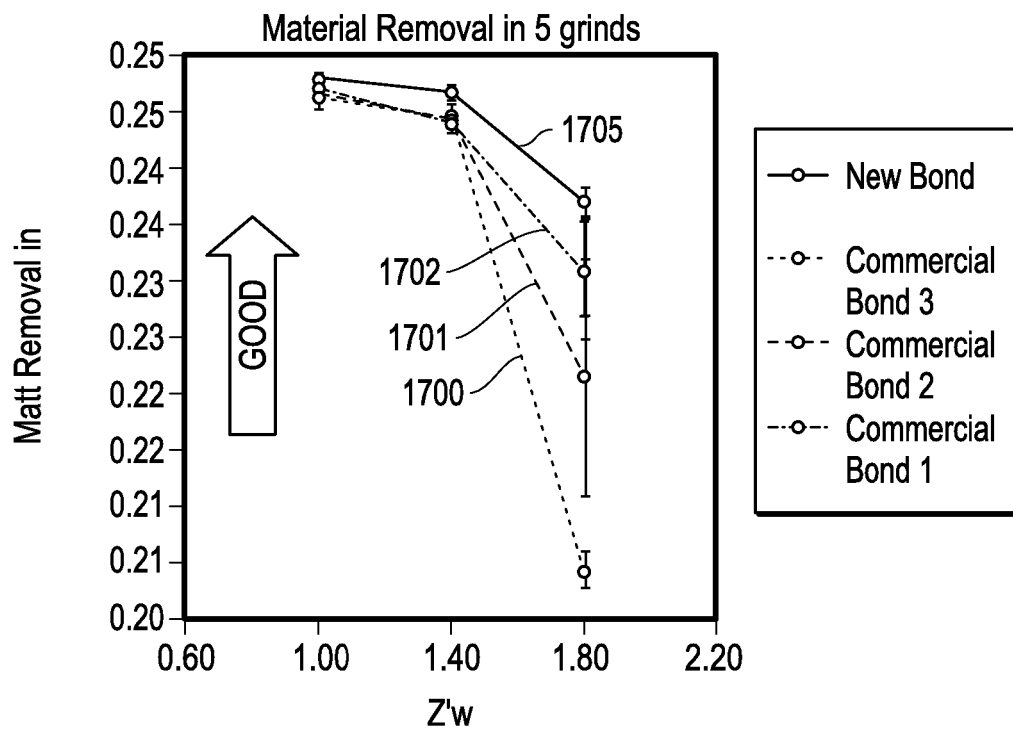


FIG. 7

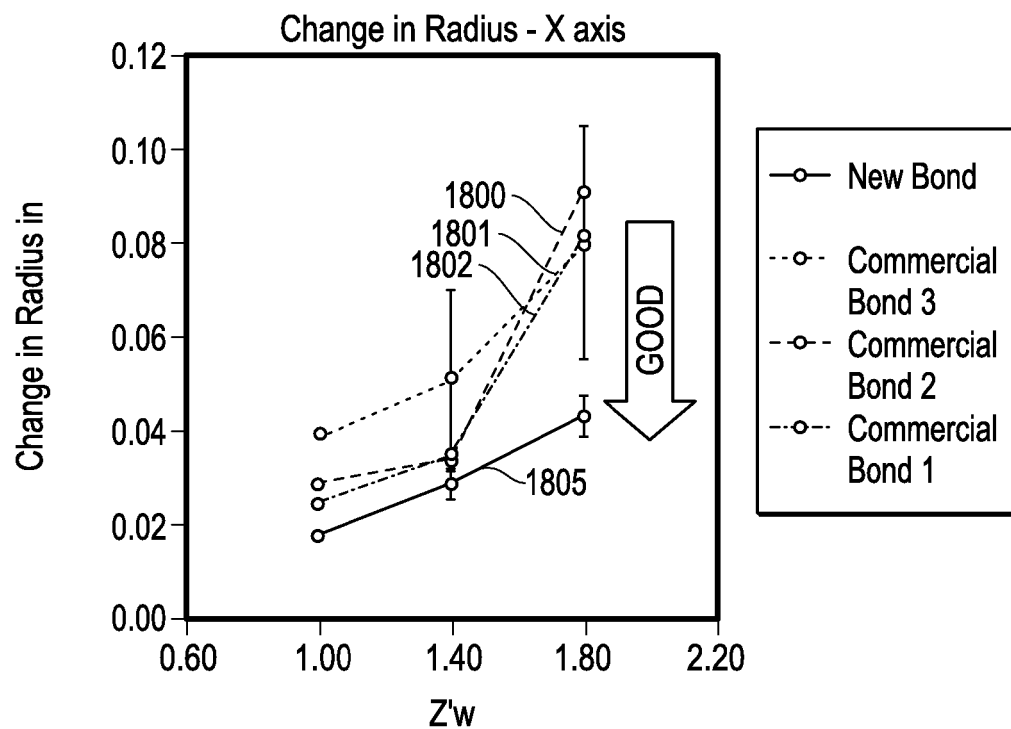


FIG. 8

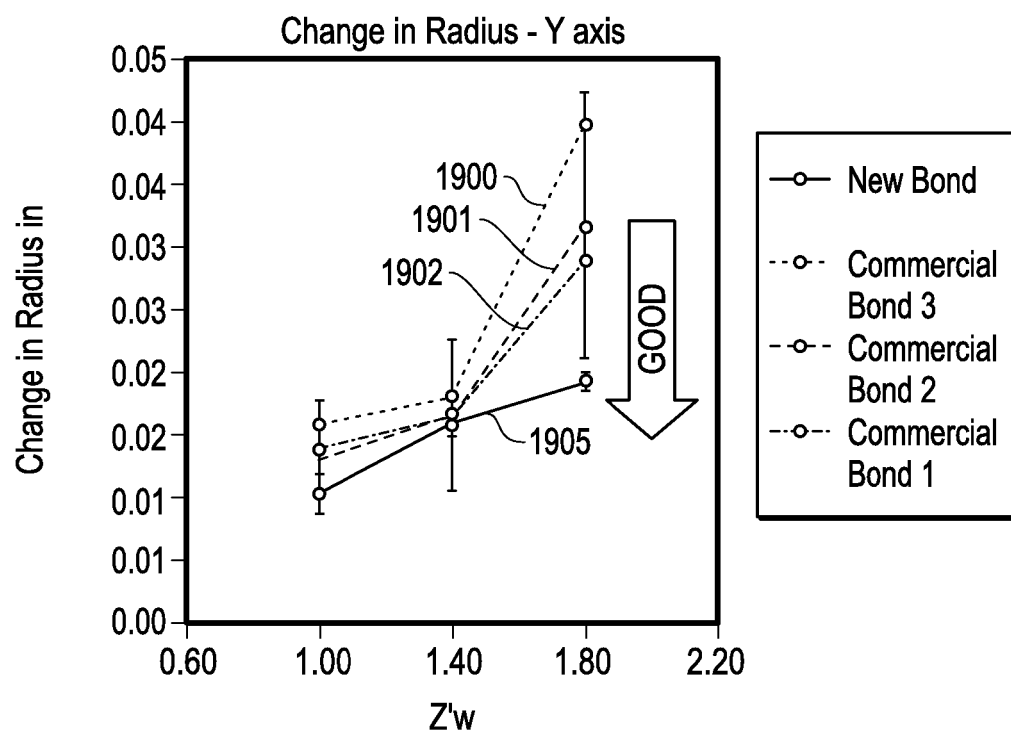
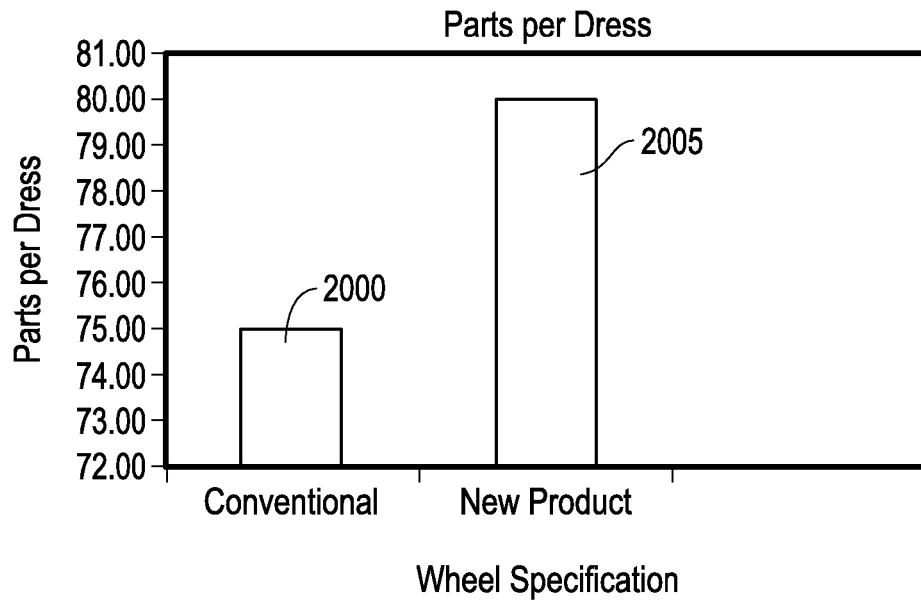
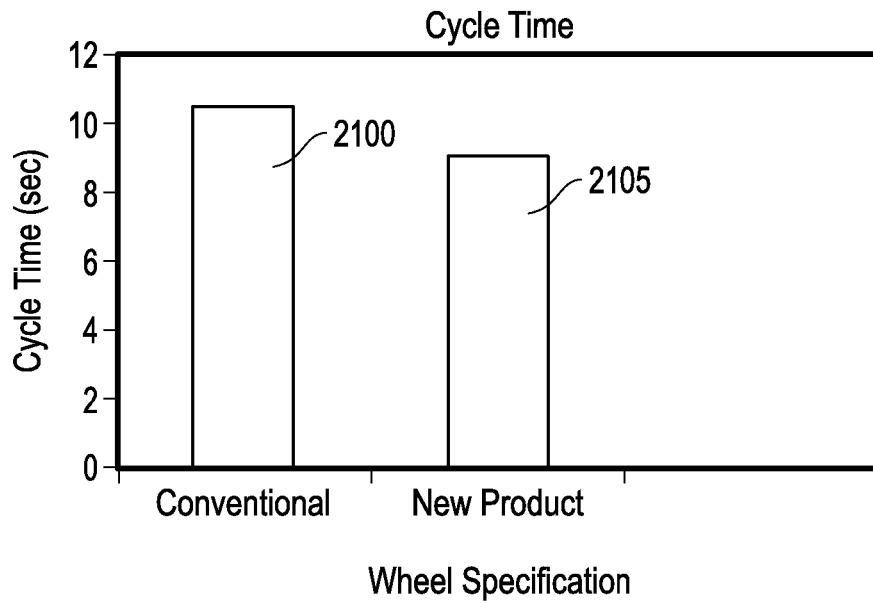


FIG. 9



*FIG. 10*



*FIG. 11*

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- US 2008222967 A1 [0001]