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(54) GRINDING WHEEL

SCHLEIFSCHEIBE

ROUE DE MEULAGE

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(73) Proprietor: **Corning Incorporated**
Corning, New York 14831 (US)

(72) Inventors:
- **BANKAITIS, Jonas**
  Horseheads
  New York 14845 (US)
- **HUZINEC, Gary Michael**
  Horseheads
  New York 14845 (US)

(74) Representative: **Epping - Hermann - Fischer**
Patentanwaltsgesellschaft mbH
Schloßschmidstraße 5
80639 München (DE)

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Description

TECHNICAL FIELD

[0001] The present disclosure generally relates to edge finishing of brittle materials, for example, and in particular, to apparatus and methods for edge finishing of glass substrates used in the manufacture of laminates.

BACKGROUND

[0002] Glass laminates can be used as windows and glazing in architectural and transportation applications, including vehicles such as automobiles, rolling stock, locomotives and airplanes. As used herein, a "glazing" refers to a transparent, semitransparent, translucent or opaque part of a window, panel, wall, enclosure, sign or other structure. Common types of glazings that are used in architectural and vehicle applications include clear and tinted laminated glass structures. Laminates made from two glass unstrengthened soda lima glass (SLG) substrates (also referred to as plies) bonded together by a polymeric interlayer such as polyvinyl butyral (PVB) can be used as architectural and vehicle glazings such as windshields, or sunroofs, as well as architectural panes and panels. Conventional vehicle glazings comprise two SLG substrates each having a thickness of about 2.1 mm or 1.6 mm bonded together by a PVB interlayer to form a laminate.

[0003] In many vehicle applications, fuel economy is a function of vehicle weight. It is desirable, therefore, to reduce the weight of glazings for such applications without compromising their strength and sound-attenuating properties. Thinner glazings or glass laminates that possess or exceed the durability, sound-damping and/or breakage performance properties associated with thicker, heavier glazings are desirable.

[0004] One way of reducing the weight of laminates is to utilize a strengthened glass substrate as one of the laminate plies, which can be strengthened chemically, thermally, mechanically or a combination to impart a surface compressive stress to the surface region that extends a distance from the surface into the glass substrate, where this distance into the glass substrate is referred to as a compressive stress depth of layer (DOL). This DOL may be a few tens of microns deep or can extend from the surface to a depth about 15% or more of the thickness, about 20% or more of the thickness, or about 21% or more of the thickness. In these strengthened glasses, the surface compressive stress induces tensile stress within the core of the material, where the resulting central tension may have central tension values of 50 MPa or greater. The strengthened substrate can be made thinner than 2.1 mm, and this thinner, strengthened substrate can be laminated with a conventional 2.1 mm thick SLG substrate. In some instances, the strengthened substrate may be thinner than 1.6 mm and can be laminated with a conventional 1.6 mm thick SLG substrate. This type of laminate may be referred to as an "Asymmetric Laminate," as defined herein.

[0005] While providing lighter weight glass laminates for use in reducing the overall weight of vehicles is desirable, such a change is subject to government regulations, manufacturer requirements, and technical considerations. For example, for automobiles, in addition to withstanding external impact requirements, an automotive glazing must withstand internal impacts and meet safety standards. The ECE R43 headform test, which simulates impact events occurring from inside a vehicle, is a regulatory test that requires that laminates for motor vehicles fracture in response to specified internal impact. The glass is required to break at a certain impact load to prevent injury.

[0006] Furthermore, each substrate of a laminate should have sufficient mechanical strength at the edges to prevent catastrophic failure during any of the corresponding fabrication and installation processing steps in high volume manufacturing. In addition, the glass laminate cannot drastically reduce visibility during and following breakage of the laminate. As noted above, an automotive glazing must withstand internal impacts and meet safety standards. Indeed, some aspects of lighter, thinner glazings that challenge manufacturers (OEMs) include wind load deflection, mechanical stiffness, ability to handle and install the individual plies without damage, and longevity in the field. Also, during the manufacture of laminates, each individual substrate is edge finished by grinding and polishing, and thinner plies present greater challenges in edge finishing. It would be desirable to provide apparatus and methods that minimize negative impacts to mechanical edge strength during finishing of brittle substrates such as glass substrates.

US 3925035 A discloses a cup-type dry grinding wheel having an abrasive section consisting of resin bond type diamond abrasive grains bonded in a metal matrix. It represents the closest prior art to the subject-matter of appended claim 1 and is the basis for its preamble.

SUMMARY

The above stated object is achieved by providing a grinding wheel according to claim 1. Preferred embodiments are set forth in the subclaims. BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Further features of embodiment of the present disclosure, their nature and various advantages will become more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, which are also illustrative of the best mode contemplated by the applicants, and in which like reference characters refer to like parts throughout, where:

FIG. 1 is a schematic drawing showing the cross-section of a glass substrate with pre-finishing edges and post-finishing edges according to one embodiment of the present disclosure;
FIG. 2 is a schematic drawing showing a glass substrate being edge finished in a first step according to one embodiment of the present invention;
FIG. 3 is a schematic drawing showing the cross-section of a grinding wheel used in one embodiment of the present disclosure;
FIG. 4 is a Weibull plot of data from Example 2;
FIG. 5 is a plot of data from Example 2;
FIG. 6 is a side view of a laminate according to one or more embodiments;
FIG. 7 is an exploded view of a laminate prior to cold-forming according to one or more embodiments;
FIG. 8 is a side view of the cold-formed laminate of FIG. 7 8 ; and
FIG. 9 is a vehicle including a laminate according to one or more embodiments.

DETAILED DESCRIPTION

[0008] As used herein, the phrase "glass laminates," which may also referred to as "laminate structures," "laminate glass structures," or "glazings," may be used as a transparent, semitransparent, translucent or opaque part of a window, panel, wall, or enclosure, for use in in architectural and vehicle or transportation applications, including automobiles, rolling stock, locomotive and airplanes, as well as buildings, signs, and other structures. Laminates according to one or more embodiments comprise at least two glass substrates, an exterior glass substrate defining an outer substrate and an internal glass substrate defining an inner substrate. In one or more embodiments, the exterior glass substrate and interior glass substrate are bonded together by an interlayer. In vehicle applications such as automotive glazings, the interior substrate is exposed to a vehicle interior and the exterior substrate faces an outside environment of the automobile.

[0009] As used herein, the phrase "Asymmetric Laminate" refers to a glass laminate that includes two glass substrates that differ from one another with respect thickness and may also differ from one another with respect to either one or both of composition, and strength. The strength parameter of an Asymmetric Laminate refers whether a glass substrate is strengthened using the processes described herein, unstrengthened (as described herein) or strengthened to a different degree than the other glass substrate. As used herein, an unstrengthened glass substrate includes a glass substrate that is annealed but not chemically, mechanically or thermally strengthened, or a glass substrate that is not annealed, chemically strengthened, mechanically strengthened or thermally strengthened.

[0010] As used herein, "metal bond diamond" is a synthesized monocrystalline diamond that has low friability compared to resin bond diamond.

[0011] As used herein, "resin bond diamond" is grown under conditions that create a plurality of tightly bonded crystals within each diamond grain and has a polycrystalline structure. Resin bond diamonds have high friability compared to metal bond diamonds.

[0012] As used herein, friability is described in Marinescu, I. (2012) Tribology of Abrasive Machining Processes., and describes the tendency of diamonds to break up into smaller fragments under pressure. As described in Marinescu at pp, "Friability is a function of the shape, integrity and purity of the crystal; properties that are themselves a consequence of the crystal growth characteristics during synthesis. Due to its adjustable brittleness and friability, synthetic diamond enlarged the application range of diamond as an abrasive. When metallic lithium is added, the grits obtained are black and opaque, due most probably to an excess of boron in the crystals. When lithium nitride is used as a solvent/catalyst, the crystals obtained are yellow and translucent. Both crystals obtained are well geometrically shaped with sharp cutting edges. The toughness or friability of the abrasive grains is not the only important characteristic of grits. Grain size, hardness, shape, specific gravity, and structure are important too." Friability is measured as described in Fracture Characteristics of Superabrasive Diamond and CBN Micron Powders, Timothy F. Dumm, 1st International Particle Technology Forum, Denver, Colorado August 17-19, 1994. Specifically, the friability measurement includes placing a set amount of a given size into a small capsule with a steel ball, and then shaking the capsule for a preset time at a controlled frequency. The broken powder is sieved on the designated sieves for that size powder and the amount of powder which is retained on the sieve is determined. The weight percent retained is then referred to as a toughness index. In general, material with a high toughness index is more resistant to impact and abrasion than material with a lower index.

[0013] Glass substrates, which are used to form laminates, typically have edge surfaces substantially orthogonal to the major surfaces. As glass substrates are cut from larger sheets, the edge surfaces may comprise micron-scale flaws such as sub-surface microcracks. If the glass substrate is subjected to a stress, the cracks may further propagate causing the glass substrate breakage. In addition, the edges form sharp corners that can easily chip and form surface-contaminating glass chips. To reduce breakage and/or to reduce chipping, the edge surfaces are typically finished using an edge finishing process to obtain a desired contour and smoothness. In addition, the edge finishing process can remove flaws from the edge surface and contour the corners.

[0014] FIG. 1 schematically illustrates a process according to a reference example for edge finishing a glass substrate using a grinding wheel according to one embodiment of the present invention. As used herein, edge finishing includes one or both grinding and polishing. Grinding removes more glass material than polishing. In this figure, an as-cut glass substrate 101 has a first major surface 103, a second major surface 105, a first pre-finishing edge surface 107 and a second pre-finishing edge surface 109 connecting the first major surface 103 with the second major surface 105. Both the pre-finishing edge surfaces 107 and 109 are substantially orthogonal to the major surfaces 103 and 105. As such, sharp corners 111, 113, 115 and 117 are defined at the intersection between the major surfaces and the pre-finishing edge surfaces. After the edge finishing steps according to various embodiments of the present disclosure, all four corners 111, 113, 115 and 117, in combination with part of the glass materials immediately below the edge surfaces 107 and 109, are removed, to form a contoured first as-finished edge surface 108 and a contoured second as-finished edge surface 110.

[0015] FIG. 2 schematically illustrates the edge finishing process according to a reference example using a grinding wheel according to an embodiment of the present invention. An as-cut glass substrate 201 having a first major surface 205, a second major surface 207 opposing the first major surface, pre-finishing edge surface 209, is subjected to edge finishing by a grinding wheel 212. In the embodiment shown in FIG. 2, the grinding wheel 212 has a pre-formed grinding wheel groove 213, which rotates around a spindle 215. During edge finishing, both corners at the intersection between the first major surface 205 and the edge surface 209 and between the second major surface 207 and the edge surface 209 are contoured simultaneously by the grinding wheel groove 213 as the grinding wheel 212 travels along the length of the first edge surface 209 . During grinding, a grinding force F(g) is applied by the grinding wheel 212 to the glass substrate 203, which allows for the removal of the glass material from the corners and the edge surface of the glass substrate. While the use of a single grinding wheel 212 is shown in FIG. 2, , multiple grinding wheels can be used. FIG. 2 shows the edge finishing of the first pre-finishing edge surface 209 only. In practice, one may edge finish the opposing second pre-finishing edge surface 208 simultaneously (not shown) or in a separate edge finishing operation.

[0016] Grinding wheels used in edge finishing of glass substrates comprise a bonded matrix structure with abrasive particles within the matrix structure. Reference to abrasive particles "within" the matrix structure refers to abrasive particles that are chemically bonded to and/or mechanically encapsulated to the matrix structure of the grinding wheel. The abrasive particles normally have a hardness that is greater than or equal to the hardness of the glass substrate. Examples of typical abrasive particles include, but are not limited to, diamond, silicon carbide (SiC), alumina (Al_2O_3), cubic boron nitride (CBN), and combinations thereof. The matrix structure holds the abrasive particles to the grinding wheel. In some embodiments, the matrix holds the abrasive particles to one another and to the grinding wheel. Examples of the material for the matrix structure include, but are not limited to, iron, stainless steel, ceramic, glass, and the like.

[0017] Embodiments of the grind wheel include abrasive particles that are specified in terms of particle size (and distribution thereof), morphology, blending in terms of relative volumes, and material type. Such embodiments enable substrates having an improved edge strength compared to substrates ground with conventional grind wheels. According to one or more embodiments, the plurality of primary abrasive particles drive material removal and material removal rate, while the less aggressive plurality of secondary abrasive particles suppress undesirable crack propagation due to brittle fracture. In one or more embodiments a quantity of tertiary abrasive is incorporated into the bond matrix to tune mechanical stiffness and bond erosion control, which fosters increased mechanical edge strength of glass substrates produced and enhancing the life of the grind wheel.

[0018] In one or more embodiments, to form the grinding wheel, the abrasive particles are mixed with the material for the matrix (in powder form). The mixture is distributed evenly around the periphery of a metal grinding wheel form, then heated to a temperature at which the metal grains begin to melt and diffuse into one another, creating a matrix structure that holds the abrasive particles to the wheel form. As used herein "metal bond matrix structure" refers to a matrix structure including a metal that bonds the abrasive particles to the grinding wheel form.

[0019] During edge finishing, the friction between the abrasive particles and the glass substrate causes the removal of a portion of the glass material from the corners and the edge surfaces of the glass substrate. In one or more embodiments, the grinding wheel and the portions of the glass substrate subjected to such edge finishing may be cooled by a fluid during edge finishing. The fluid may be a liquid such as water.

[0020] FIG. 3 shows an exemplary embodiment of a grinding wheel 410 comprised of a matrix structure 412 with a grinding surface 403. The grinding wheel 410 further comprises a plurality of primary abrasive particles 401 and a plurality of secondary abrasive particles 402 within the matrix structure 412. In one or more embodiments, the primary abrasive particles 401 have a primary particle size and the secondary abrasive particles 402 have a secondary particle size. As used herein, the phrase "particle size" refers to the longest cross-sectional dimension of the particle. For example, when the particles are spherical, the particle size is the diameter of the particle. When the particles are cubes, then the particle size is the length of the diagonal of the cube.

[0021] The primary particle size and the secondary particle size may differ from one another. In one or more embodiments, the secondary particle size is less than or equal to the primary particle size. In one or more embodiments, at least 40% (or at least 50%, at least 60%, at least 70% or at least 80%) of the second abrasive particles have a secondary particle size that is equal to or less than the primary particle size of at least 40% (or at least 50%, at least 60%, at least 70% or at least 80%) of the primary second abrasive particles. For example, at least 40% of the secondary abrasive particles may have a secondary particle size that may be in a range from about 20 microns to about 30 microns, and at least 40% of the primary abrasive particles has a primary particle size that may be in a range from about 30 microns to about 40 microns.

[0022] In one or more embodiments, the primary abrasive particle size is in a range from about 30 microns to about 100 microns, from about 30 microns to about 90 microns, from about 30 microns to about 80 microns, from about 30 microns to about 70 microns, from about 30 microns to about 60 microns, from about 30 microns to about 50 microns, from about 30 microns to about 40 microns, from about 40 microns to about 100 microns, from about 50 microns to about 100 microns, from about 60 microns to about 100 microns, from about 70 microns to about 100 microns, from about 80 microns to about 100 microns, from about 90 microns to about 100 microns, from about 30 microns to about 40 microns, from about 40 microns to about 50 microns, from about 40 microns to about 60 microns, from about 40 microns to about70 microns, from about 40 microns to about 80 microns, from about 40 microns to about 90 microns, from about 50 microns to about 60 microns, from about 50 microns to about 70 microns, from about 50 microns to about 80 microns, or from about 50 microns to about 90 microns.

[0023] In one or more embodiments, the secondary abrasive particle size is in a range from about 20 microns to about 50 microns, from about 22 microns to about 50 microns, from about 24 microns to about 50 microns, from about 25 microns to about 50 microns, from about 26 microns to about 50 microns, from about 28 microns to about 50 microns, from about 30 microns to about 50 microns, from about 32 microns to about 50 microns, from about 34 microns to about 50 microns, from about 35 microns to about 50 microns, from about 36 microns to about 50 microns, from about 38 microns to about 50 microns, from about 40 microns to about 50 microns, from about 20 microns to about 48 microns, from about 20 microns to about 46 microns, from about 20 microns to about 45 microns, from about 20 microns to about 44 microns, from about 20 microns to about 42 microns, from about 20 microns to about 40 microns, from about 20 microns to about 38 microns, from about 20 microns to about 36 microns, from about 20 microns to about 35 microns, from about 20 microns to about 34 microns, from about 20 microns to about 32 microns, from about 20 microns to about 30 microns, from about 30 microns to about 40 microns, or from about 15 microns to about 30 microns; however, as noted above the secondary abrasive particle size is less than or equal to the primary abrasive particle size.

[0024] In one or more embodiments, the grinding wheel 410 may further comprise tertiary abrasive particles within the matrix structure and having a tertiary particle size. In one or more embodiments, the tertiary particle size is less than or equal to the secondary particle size. In one or more embodiments, the tertiary particle size is in a range from about 1 micron to about 20 microns, from about 1 micron to about 18 microns, from about 1 micron to about 16 microns, from about 1 micron to about 15 microns, from about 1 micron to about 14 microns, from about 1 micron to about 12 microns, from about 1 micron to about 10 microns, from about 2 microns to about 20 microns, from about 4 microns to about 20 microns, from about 5 microns to about 20 microns, from about 6 microns to about 20 microns, from about 8 microns to about 20 microns, from about 10 microns to about 20 microns, or from about 4 microns to about 8 microns; however, as noted above the tertiary abrasive particle size is less than or equal to the second abrasive particle size. The tertiary abrasive particles are not shown in FIG. 3, but the tertiary abrasive particles would be within the matrix structure 412. In some embodiments, the tertiary abrasive particles may be highly thermally conductive. Without being bound by theory, it is believed the use of the tertiary abrasive particles described herein increases the overall conductivity of the matrix structure and controls bond erosion thereby enhancing grind wheel life.

[0025] In one or more embodiment, the matrix structure is a metal bond matrix structure. In one or more particular embodiments, the metal bond matrix structure comprises any one or more of iron, stainless steel, ceramic, glass, and the like. In one or more embodiments, the matrix structure comprises iron, includes an iron bond matrix structure or is an iron bond matrix structure.

[0026] In one or more embodiments, the grinding wheel defines a grinding wheel volume. In one or more embodiments, the matrix structure comprises from about 60 volume % to about 90 volume % (e.g., from about 60 volume % to about 85 volume %, from about 60 volume % to about 80 volume %, from about 60 volume % to about 75 volume %, from about 60 volume % to about 70 volume %, from about 60 volume % to about 65 volume %, from about 65 volume % to about 90 volume %, from about 70 volume % to about 90 volume %, from about 75 volume % to about 90 volume %, or from about 80 volume % to about 90 volume %) of the grinding wheel volume.

[0027] In one or more embodiments, the abrasive diamond particles comprise a total abrasive particle volume. In one or more embodiments, the total abrasive particle volume includes combined volume of the primary abrasive particles and the secondary abrasive particles. As will be described below, the grinding wheel may include tertiary abrasive particles and the total abrasive particle volume includes the combination of the primary abrasive particles, the secondary abrasive particles and the tertiary abrasive particles. In one or more embodiments, the total abrasive particle volume comprises from about 5% to about 35% by volume of the grind wheel volume. In one or more embodiments, the total abrasive particle volume comprises from about 5% to about 30% by volume, from about 5 % to about 25% by volume, from about 5% to about 20% by volume, from about 5% to about 15% by volume, from about 10% to 35% by volume, from about 10% to about 30% by volume, from about 10% to about 25% by volume, or from about 10% to about 20% by volume, of the grind wheel volume.

[0028] In one or more embodiments, the total abrasive particle volume comprises about 25% to 35 % of the combined total abrasive particle volume and matrix structure volume. For example, in one or more specific embodiments, the total abrasive particle volume comprises an industry standard "125" or 31.25% by volume of the combined total abrasive particle volume and matrix structure (with the matrix structure comprising the remaining 68.75% of the combined volume).

[0029] In one or more embodiments, the primary abrasive diamond particles and secondary abrasive particles, in combination, comprise from about 10 volume % to about 40 volume % of the grinding wheel volume. For example, the primary abrasive diamond particles and secondary abrasive particles, in combination, comprise from about 15 volume % to about 40 volume %, from about 20 volume % to about 40 volume %, from about 25 volume % to about 40 volume %, from about 30 volume % to about 40 volume %, from about 15 volume % to about 40 volume %, from about 15 volume % to about 40 volume %, from about 15 volume % to about 35 volume %, from about 15 volume % to about 30 volume %, from about 15 volume % to about 25 volume %, or from about 15 volume % to about 20 volume %, of the grinding wheel volume.

[0030] In one or more embodiments, the primary abrasive particles comprise from about 51% to 97% of the total abrasive diamond particle volume. In some instances, the primary abrasive particles comprise from about 55 % to about 97%, from about 60 % to about 97%, from about 65 % to about 97%, from about 70 % to about 97%, from about 75 % to about 97%, from about 80 % to about 97%, from about 85 % to about 97%, from about 90 % to about 97%, from about 51 % to about 95%, from about 51 % to about 90%, from about 51 % to about 85%, from about 51 % to about 80%, from about 51 % to about 75%, from about 51 % to about 70%, from about 51 % to about 65%, from about 51 % to about 60%, from about 51 % to about 55%, from about 60% to about 95%, from about 60% to about 90%, from about 60% to about 80%, from about 60% to about 75%, from about 60% to about 70%, or from about 65% to about 75%, of the total abrasive particle volume. In one or more embodiments, he primary abrasive particles comprise about 70% of the total abrasive diamond particle volume (or about 24.31% volume fraction of overall grind wheel volume, including the metal bond matrix structure).

[0031] In one or more embodiments, the secondary particles comprise from about 2% to about 48% of the total abrasive diamond particle volume. For example, the secondary particles of one or more embodiments comprise from about 4% to about 48%, from about 5% to about 48%, from about 6% to about 48%, from about 8% to about 48%, from about 10% to about 48%, from about 12% to about 48%, from about 14% to about 48%, from about 15% to about 48%, from about 16% to about 48%, from about 18% to about 48%, from about 20% to about 48%, from about 22% to about 48%, from about 24% to about 48%, from about 25% to about 48%, from about 4% to about 46%, from about 4% to about 45%, from about 4% to about 44%, from about 4% to about 42%, from about 4% to about 40%, from about 4% to about 38%, from about 4% to about 36%, from about 4% to about 35%, from about 4% to about 34%, from about 4% to about 32%, from about 4% to about 30%, from about 5% to about 45%, from about 5% to about 40%, from about 5% to about 30%, from about 5% to about 20%, from about 5% to about 10%, from about 10% to about 48%, from about 10% to about 45%, from about 10% to about 40%, from about 10% to about 30%, from about 10% to about 20%, from about 20% to about 48%, from about 20% to about 45%, from about 20% to about 40%, from about 20% to about 30%, or from about 25% to about 35%, of the total abrasive diamond particle volume.

[0032] In one or more embodiments, the tertiary abrasive particles comprise from about 1% to about 5% of the total abrasive diamond particle volume. For example, the tertiary abrasive particles comprise from about 1.1% to about 5%, from about 1.15% to about 5%, from about 1.2% to about 5%, from about 1.25% to about 5%, from about 1.3% to about 5%, from about 1.35% to about 5%, from about 1.4% to about 5%, from about 1.45% to about 5%, from about 1.5% to about 5%, from about 1.55% to about 5%, from about 1.6% to about 5%, from about 1.65% to about 5%, from about 1.7% to about 5%, from about 1.75% to about 5%, from about 1.8% to about 5%, from about 1.85% to about 5%, from about 1.9% to about 5%, from about 1.95% to about 5%, from about 2% to about 5%, from about 2.5% to about 5%, from about 3% to about 5%, from about 41% to about 5%, from about 1% to about 4.5%, from about 1% to about 4 %, from about 1% to about 3.5%, from about 1% to about 3%, from about 1% to about 2.5%, from about 1% to about 2%, or from about 1% to about 1.5%, of the total abrasive diamond particle volume.

[0033] According to the present invention, the plurality of primary abrasive particles comprises resin bond diamond particles and the plurality of secondary abrasive particles comprises metal bond diamond particles, or

the plurality of secondary abrasive particles comprises resin bond diamond particles and the plurality of primary abrasive particles comprises metal bond diamond particles.

[0034] In one or more embodiments, the primary abrasive particles comprise metal bond diamond particles, the secondary abrasive particles comprise resin bond diamond particles, and the tertiary abrasive particles comprise silicon carbide.

[0035] The morphology of the plurality of primary abrasive particles, the plurality of secondary abrasive particles, and the plurality of tertiary abrasive particles can be characterized a morphology index or a "tau" parameter. One morphology type is cubic, which has a morphology index of 0/8 and a tau parameter of 1.00. Another morphology type is octahedral, which has a morphology index of 8/8 and a tau parameter of 0.0. Cubo-octahedral morphologies have a morphology index of 2/8, 4/8, or 6/8 and tau parameters of 0.75, 0.50 and 0.25, respectively. Image analysis techniques can measure diamond particle morphology indices to specify whether the morphology is cubic, octahedral, cubo-octahedral or other shape. According to one or more embodiments, the primary and secondary abrasive particles have a morphology index or tau parameter that are different from each other.

[0036] In one or more embodiments, the primary abrasive particles may comprise particles having a cubo-octahedral-morphology. In some instances, at least 50% (e.g., about 55% or more, about 60% or more, about 65% or more, about 70% or more, about 75% or more, about 80% or more, about 85% or more, about 90% or more) of the primary abrasive particles have a cubo-octahedral morphology. In one or more embodiments, the secondary abrasive particles may comprise particles having a morphology that is not cubo-octahedral. In some instances, at least 50% (e.g., about 55% or more, about 60% or more, about 65% or more, about 70% or more, about 75% or more, about 80% or more, about 85% or more, about 90% or more) of the secondary abrasive particles have a morphology that is not cubo-octahedral.

[0037] In one or more embodiments, the secondary abrasive particles may comprise particles having a cubo-octahedral-morphology. In some instances, at least 50% (e.g., about 55% or more, about 60% or more, about 65% or more, about 70% or more, about 75% or more, about 80% or more, about 85% or more, about 90% or more) of the secondary abrasive particles have a cubo-octahedral morphology. In one or more embodiments, the primary abrasive particles may comprise particles having a morphology that is not cubo-octahedral. In some instances, at least 50% (e.g., about 55% or more, about 60% or more, about 65% or more, about 70% or more, about 75% or more, about 80% or more, about 85% or more, about 90% or more) of the primary abrasive particles have a morphology that is not cubo-octahedral.

[0038] In one or more embodiments, the grind wheel comprises an iron bond matrix structure and a plurality of abrasive particle, which include a plurality of primary abrasive particles, a plurality of secondary abrasive particles, and a plurality of tertiary abrasive particles. In one or more such embodiments, the tertiary abrasive particles include metal bond diamond abrasive particles. In one or more embodiments, tertiary abrasive particles comprise about 1.25% of total abrasive particle volume. In one or more such embodiments, the plurality of primary abrasive particles comprises metal bond diamond particles and comprises 70% of the total abrasive particle volume (or 12.64% volume fraction of overall grind wheel volume). In one or more such embodiments, the plurality of secondary abrasive particles comprises resin bond diamond particles and comprises about 30% of the total abrasive particle volume (or 3.61% volume fraction of overall grind wheel volume). In one or more embodiments, the primary abrasive is cubo-octahedral providing high fracture toughness thereby boosting grind speed capability while increasing wheel life. The total abrasive particle volume comprises about 17.5% by volume of the combination of total abrasive particle volume and matrix structure.

[0039] In one or more embodiments, the plurality of tertiary abrasive particles comprises approximately 1.25% of total abrasive particle volume; the plurality of primary abrasive particle comprises metal bond diamond particles, has a primary abrasive particle size from about 30 microns to about 40 microns and comprises 70% of the total abrasive particle volume (or 16.25% volume of grind wheel volume); and the plurality of secondary abrasive particles comprises silicon carbide particles, and comprises about 15% of the total abrasive particle volume (or 3.61% volume of the combined total abrasive particle volume and matrix structure volume). Such silicon carbide particles can have particles size specifications of d_{03}=37.0 μm, d_{50}=17.9 μm ± 1.3 μm, d_{94}=11.0 μm, and a maximum particle size = 45.0 μm. The total abrasive particle volume in this embodiment is an industry standard "125" or 31.25% by volume of the combined total abrasive particle volume and matrix structure.

[0040] A reference exampleof this disclosure not falling under the scope of the appended claims pertains to a method of finishing an edge of glass substrate comprising edge finishing the edge with one or more embodiments of the grinding wheel described herein to form an edge finished-edge. In one or more embodiments, edge finishing comprises grinding the edge. In one or more embodiments, edge finishing includes polishing the edge. In one or more specific embodiments, the edge finishing comprises grinding and polishing the edge. In one or more embodiments, the glass substrate comprises a soda lime silicate composition. Such substrate may be annealed. In some embodiments, the substrate may be un-strengthened, but annealed as described herein. In one or more embodiments, the substrate may be strengthened by thermal, chemical (e.g., by ion exchange) or a combination of thermal and chemical processes. In one or more embodiments, the glass substrate with the edge finished-edge exhibits a mechanical edge strength exceeding 110 MPa as measured by a four point bend test. In one or more embodiments, the mechanical edge strength may be about 130 MPa or greater.

[0041] Glass sheets or substrates, particularly relatively thick (e.g., 1.6 mm or greater) unstrengthened glass substrates, can be edge finished according to the embodiments described above. Such glass sheets or substrates may be used in Asymmetric Laminates as described herein.

[0042] As a laminate is made thinner, mechanical stiffness of the laminate decreases, effectively transferring mechanical stress during bending to the edges of the laminate. In Asymmetric Laminates, surprisingly, it has been determined that edge strength suffers considerably, and the mode of failure during bend (e.g., four-point bend testing according to ASTM C 158-02 or three-point bend testing) testing occurs in the thicker substrate rather than the thinner substrate. This particular phenomenon is observed when the thicker substrate is unstrengthened (but may be annealed) and the thinner substrate is strengthened..

[0043] This failure mode was observed when subjecting an Asymmetric Laminate (comprising a 2.1 mm-thick SLG substrate, an PVB interlayer having a thickness of 0.8 mm, and a chemically strengthened glass substrate having a thickness of 0.7 mm) and a symmetric laminate (comprising two 2.1 mm-thick SLG substrates and an intervening PVB interlayer having a thickness of 0.8 mm). In particular, the Asymmetric Laminate showed greater failure at the edges of the laminate. Furthermore, Weibull analysis showed the Asymmetric Laminate exhibited a 35% reduction in mechanical edge strength compared with the symmetric laminate. Additional three point bend testing at the edges of several samples of the Asymmetric Laminate including a a relatively thick, unstrengthened SLG substrate, an intervening PVB interlayer,and a thinner chemically strengthened glass substrate revealed a high rate of failure below a targeted force of 36 psi.

[0044] It was determined that increasing the edge strength of the unstrengthened thicker glass substrate improved the edge strength of the entire Asymmetric Laminate, especially when the Asymmetric Laminate includes a thin, strengthened glass substrate.

[0045] A reference example pertains to a laminate as shown in FIG. 6, exhibiting improved edge strength. In one or more embodiments, the laminate 500 includes a first glass substrate 530 having a first major surface 532, an opposing second major surface 534 defining a first thickness, and a second strengthened glass substrate 510 having a first major surface 535, an opposing second major surface 537 defining a second thickness, wherein the first glass substrate has a first thickness greater than the strengthened glass substrate second thickness. In one or more embodiments, the first glass substrate is unstrengthened (i.e., is not thermally, mechanically or chemically strengthened) but may be annealed. As shown in FIG. 6, the laminate 500 includes an interlayer 520 is disposed between the first and second glass substrates.

[0046] In one or more reference examples, the laminate exhibits a mechanical edge strength of about 32.7 lbf or more, as measured by three point bend testing. In one or more embodiments, the first glass substrate comprises an edge 540 that is edge-finished using the grind wheel and/or methods described herein, the edge-finished edge 540 exhibits a mechanical edge strength of about 80 MPa or greater, about 85 MPa or greater, about 90 MPa or greater, about 95 MPa or greater, about 100 MPa or greater, about 105 MPa or greater, about 110 MPa or greater, about 115 MPa or greater, about 120 MPa or greater, about 125 MPa or greater, about 130 MPa or greater, as measured by a four point bend test. Without being bound by theory, it is believed that the mechanical edge strength of a thinner, strengthened glass substrate was much greater than the thicker and unstrengthened glass substrate, and, surprisingly, it was observed that the mechanical strength of the laminate incorporating such glass substrates was directly proportional to the edge strength of the thicker unstrengthened glass substrate and not the thinner, strengthened glass substrate. Accordingly, the first glass substrate (which is thicker than the second glass substrate and is unstrengthened) exhibits a mechanical edge strength in a range from about 100 MPa to about 150 MPa, from about 110 MPa to about 150 MPa, from about 120 MPa to about 150 MPa, from about 130 MPa to about 150 MPa, from about 140 MPa to about 150 MPa, from about 100 MPa to about 140 MPa, from about 100 MPa to about 130 MPa, from about 100 MPa to about 120 MPa, from about 100 MPa to about 110 MPa, from about 120 MPa to about 140 MPa, or from about 120 MPa to about 130 MPa, as measured using a four-point bend test.

[0047] In one or more reference examples, the ratio of the first thickness to the second thickness is at least 10:1, or at least 9:1, or at least 8:1, or at least 7:1, or at least 6:1, or at least 5:1, or at least 4:1, or at least 3:1, or at least 2:1. In one or more embodiments, the ratio of the first thickness to the second thickness is in the range of about 2:1 to about 10:1, or in the range of about 2:1 to about 9:1, or in the range of about 2:1 to about 8:1, or in the range of about 3:1 to about 10:1, or in the range of about 3:1 to about 9:1, or in the range of about 3:1 to about 8:1, or in the range of about 4:1 to about 10:1, or in the range of about 4:1 to about 9:1, or in the range of about 4:1 to about 8:1, or in the range of about 5:1 to about 10:1, or in the range of about 5:1 to about 9:1, or in the range of about 5:1 to about 8:1.

[0048] In one or more reference examples, the first glass substrate has a thickness that is about 1.6 mm or greater. In such embodiments, the first glass substrate has a thickness that is about 1.7 mm or greater, about 1.75 mm or greater, about 1.8 mm or greater, about 1.7 mm or greater, about 1.7 mm or greater, about 1.7 mm or greater, about 1.85 mm or greater, about 1.9 mm or greater, about 1.95 mm or greater, about 2 mm or greater, about 2.1 mm or greater, about 2.2 mm or greater, about 2.3 mm or greater, about 2.4 mm or greater, 2.5 mm or greater, 2.6 mm or greater, 2.7 mm or greater, 2.8 mm or greater, 2.9 mm or greater, 3 mm or greater, 3.2 mm or greater, 3.4 mm or greater, 3.5 mm or greater, 3.6 mm or greater, 3.8 mm or greater, 4 mm or greater, 4.2 mm or greater, 4.4 mm or greater, 4.6 mm or greater, 4.8 mm or greater, 5 mm or greater, 5.2 mm or greater, 5.4 mm or greater, 5.6 mm or greater, 5.8 mm or greater, or 6 mm or greater. In some embodiments the first glass substrate has a thickness in a range from about 1.6 mm to about 6 mm, from about 1.7 mm to about 6 mm, from about 1.8 mm to about 6 mm, from about 1.9 mm to about 6 mm, from about 2 mm to about 6 mm, from about 2.1 mm to about 6 mm, from about 2.2 mm to about 6 mm, from about 2.3 mm to about 6 mm, from about 2.4 mm to about 6 mm, from about 2.5 mm to about 6 mm, from about 2.6 mm to about 6 mm, from about 2.8 mm to about 6 mm, from about 3 mm to about 6 mm, from about 3.2 mm to about 6 mm, from about 3.4 mm to about 6 mm, from about 3.6 mm to about 6 mm, from about 3.8 mm to about 6 mm, from about 4 mm to about 6 mm, from about 1.6 mm to about 5.8 mm, from about 1.6 mm to about 5.6 mm, from about 1.6 mm to about 5.5 mm, from about 1.6 mm to about 5.4 mm, from about 1.6 mm to about 5.2 mm, from about 1.6 mm to about 5 mm, from about 1.6 mm to about 4.8 mm, from about 1.6 mm to about 4.6 mm, from about 1.6 mm to about 4.4 mm, from about 1.6 mm to about 4.2 mm, from about 1.6 mm to about 4 mm, from about 3.8 mm to about 5.8 mm, from about 1.6 mm to about 3.6 mm, from about 1.6 mm to about 3.4 mm, from about 1.6 mm to about 3.2 mm, or from about 1.6 mm to about 3 mm.

[0049] In one or more reference example embodiments, the second glass ubstrate has a thickness thickness less than 1.6 mm (e.g., 1.55 mm or less, 1.5 mm or less, 1.45 mm or less, 1.4 mm or less, 1.35 mm or less, 1.3 mm or less, 1.25 mm or less, 1.2 mm or less, 1.15 mm or less, 1.1 mm or less, 1.05 mm or less, 1 mm or less, 0.95 mm or less, 0.9 mm or less, 0.85 mm or less, 0.8 mm or less, 0.75 mm or less, 0.7 mm or less, 0.65 mm or less, 0.6 mm or less, 0.55 mm or less, 0. 5mm or less, 0.45 mm or less, 0. 4 mm or less, 0.35 mm or less, 0. 3 mm or less, 0.25 mm or less, 0.2 mm or less, 0.15 mm or less, or about 0.1 mm or less). The lower limit of thickness may be 0.1 mm, 0. 2mm or 0.3 mm. In some embodiments, the thickness of the second glass substrate is in the range from about 0.1 mm to less than about 1.6 mm, from about 0.1 mm to about 1.5 mm, from about 0.1 mm to about 1.4 mm, from about 0.1 mm to about 1.3 mm, from about 0.1 mm to about 1.2 mm, from about 0.1 mm to about 1.1 mm, from about 0.1 mm to about 1 mm, from about 0.1 mm to about 0.9 mm, from about 0.1 mm to about 0.8 mm, from about 0.1 mm to about 0.7 mm, from about 0.1 mm, from about 0.2 mm to less than about 1.6 mm, from about 0.3 mm to less than about 1.6 mm, from about 0.4 mm to less than about 1.6 mm, from about 0.5 mm to less than about 1.6 mm, from about 0.6 mm to less than about 1.6 mm, from about 0.7 mm to less than about 1.6 mm, from about 0.8 mm to less than about 1.6 mm, from about 0.9 mm to less than about 1.6 mm, or from about 1 mm to about 1.6 mm.

[0050] In one or more reference examples, the laminate has a thickness of 6.85 mm or less, or 5.85 mm or less, where the thickness comprises the sum of thicknesses of the first glass substrate, the second glass substrate, and the interlayer. In various embodiments, the laminate may have a thickness in the range of about 1.8 mm to about 6.85 mm, or in the range of about 1.8 mm to about 5.85 mm, or in the range of about 1.8 mm to about 5.0 mm, or 2.1 mm to about 6.85 mm, or in the range of about 2.1 mm to about 5.85 mm, or in the range of about 2.1 mm to about 5.0 mm, or in the range of about 2.4 mm to about 6.85 mm, or in the range of about 2.4 mm to about 5.85 mm, or in the range of about 2.4 mm to about 5.0 mm, or in the range of about 3.4 mm to about 6.85 mm, or in the range of about 3.4 mm to about 5.85 mm, or in the range of about 3.4 mm to about 5.0 mm.

[0051] In one or more reference examples, the laminate exhibits radii of curvature that is less than 1000 mm, or less than 750 mm, or less than 500 mm, or less than 300 mm. The laminate, the first glass substrate and/or the second glass substrate are substantially free of wrinkles.

[0052] In one or more reference examples, the interlayer may include a single layer or multiple layers. The interlayer 520 (or layers thereof) may be formed polymers such as polyvinyl butyral (PVB), acoustic PBV (APVB), ionomers, ethylene-vinyl acetate (EVA) and thermoplastic polyurethane (TPU), polyester (PE), polyethylene terephthalate (PET) and the like. The thickness of the interlayer may be in the range from about 0.5 mm to about 2.5 mm, from about 0.8 mm to about 2.5 mm, from about 1 mm to about 2.5 mm or from about 1.5 mm to about 2.5 mm.

[0053] In one or more reference examples, one or more of interlayer 520, first glass substrate 430, and second glass substrate 510 comprise a first edge (e.g., 540) with a first thickness and a second edge (e.g., 542) opposite the first edge with a second thickness greater than the first thickness.

[0054] In one or more reference examples, the second glass substrate may be cold-formed (with an intervening interlayer). In an exemplary cold-formed laminate shown in FIGS. 7-8, a second glass substrate 610 is laminated to a relatively thicker and curved first glass substrate 630 having an edge-finished edge 640. In FIG. 7, first glass substrate 630 includes a first surface 632 and a second surface 634 in contact with an interlayer 620, and the second glass substrate 610 includes a third surface 612 in contact with the interlayer 620 and a fourth surface 614. An indicator of a cold-formed laminate is the fourth surface 614 has a greater surface compressive stress (as described herein) than the third surface 612. Accordingly, a cold-formed laminate can comprise a high compressive stress level on fourth surface 614 making this surface more resistant to fracture.

[0055] In one or more reference examples, prior to the cold-forming process, the respective compressive stresses in the third surface 612 and fourth surface 614 are substantially equal. In one or more embodiments in which the second glass substrate is strengthened (as described herein), the third surface 612 and the fourth surface 614 exhibit substantially equal compressive stress with respect to one another, prior to cold-forming. In one or more embodiments, after cold-forming, the compressive stress on the fourth surface 614 increases (i.e., the compressive stress on the fourth surface 614 is greater after cold-forming than before cold-forming). Without being bound by theory, the cold-forming process increases the compressive stress of the glass substrate being shaped (i.e., the second glass substrate) to compensate for tensile stresses imparted during bending and/or forming operations. In one or more embodiments, the cold-forming process causes the third surface of that glass substrate (i.e., the third surface 612) to experience tensile stresses, while the fourth surface of the glass substrate (i.e., the fourth surface 614) experiences compressive stresses.

[0056] When a strengthened second glass substrate 610 is utilized, the third and fourth surfaces (612, 614) are already under compressive stress, and thus the third surface 612 can experience greater tensile stress. This allows for the strengthened second glass substrate 610 to conform to more tightly curved surfaces.

[0057] In one or more reference examples, the second glass substrate 610 has a thickness less than the first glass substrate 630. This thickness differential means the second glass susbtrate 610 is more flexible to conform to the shape of the first glass substrate 630.

[0058] In some reference examples, the cold-formed laminate 600 may be formed using an exemplary cold forming process that is performed at a temperature at or just above the softening temperature of the interlayer material (e.g., 420) (e.g., about 100 °C to about 120 °C), that is, at a temperature less than the softening temperature of the respective glass substrate. In one embodiment as shown in FIG. 7, the cold-formed laminate may be formed by: placing an interlayer between the first glass substrate (which is curved) and a second glass substrate (which may be flat) to form a stack; applying pressure to the stack to press the second glass substrate against the interlayer layer which is pressed against the first glass substrate; and heating the stack to a temperature below 400° C to form the cold-formed laminate in which the second glass substrate conforms in shape to the first glass substrate. Such a process can occur using a vacuum bag or ring in an autoclave or another suitable apparatus. The stress of an exemplary second glass substrate 610 may change from substantially symmetrical to asymmetrical according to some embodiments of the present disclosure.

[0059] As used herein, "flat" and "planar" are used interchangeably and mean a shape having curvature less than a curvature at which lamination defects are created due to curvature mismatch, when such a flat substrate is cold-formed to another substrate (i.e., a radius of curvature of greater than or equal to about 3 meters, greater than or equal to about 4 meters or greater than or equal to about 5 meters) or a curvature (of any value) along only one axis. A flat substrate has the foregoing shape when placed on a surface. As used herein "complex curve" and "complexly curved" mean a non-planar shape having curvature along two orthogonal axes that are different from one another. Examples of complexly curved shapes includes having simple or compound curves, also referred to as non-developable shapes, which include but are not limited to spherical, aspherical, and toroidal. The complexly curved laminates according to embodiments may also include segments or portions of such surfaces, or be comprised of a combination of such curves and surfaces. In one or more embodiments, a laminate may have a compound curve including a major radius and a cross curvature. A complexly curved laminate according to one or more embodiments may have a distinct radius of curvature in two independent directions. According to one or more embodiments, complexly curved laminates may thus be characterized as having "cross curvature," where the laminate is curved along an axis (i.e., a first axis) that is parallel to a given dimension and also curved along an axis (i.e., a second axis) that is perpendicular to the same dimension. The curvature of the laminate can be even more complex when a significant minimum radius is combined with a significant cross curvature, and/or depth of bend. Some laminates may also include bending along axes that are not perpendicular to one another. As a non-limiting example, the complexly-curved laminate may have length and width dimensions of 0.5 m by 1.0 m and a radius of curvature of 2 to 2.5 m along the minor axis, and a radius of curvature of 4 to 5 m along the major axis. In one or more embodiments, the complexly-curved laminate may have a radius of curvature of 5 m or less along at least one axis. In one or more embodiments, the complexly-curved laminate may have a radius of curvature of 5 m or less along at least a first axis and along the second axis that is perpendicular to the first axis. In one or more embodiments, the complexly-curved laminate may have a radius of curvature of 5 m or less along at least a first axis and along the second axis that is not perpendicular to the first axis.

[0060] In one or more reference examples the laminate has a complexly curved shape and may optionally be cold-formed.

[0061] A reference example of this disclosure pertains to a vehicle that includes the laminate described herein. For example, as shown in FIG. 9 shows a vehicle 700 comprising a body 710 defining an interior, at least one opening 720 in communication with the interior, and a window disposed in the opening, wherein the window comprises a laminate, according to one or more embodiments described herein. The laminate may form the sidelights, windshields, rear windows, windows, rearview mirrors, and sunroofs in the vehicle. In some embodiments, the laminate 700 may form an interior partition (not shown) within the interior of the vehicle, or may be disposed on an exterior surface of the vehicle and form an engine block cover, headlight cover, taillight cover, or pillar cover. In one or more embodiments, the vehicle may include an interior surface (not shown, but may include door trim, seat backs, door panels, dashboards, center consoles, floor boards, and pillars), and the laminate described herein is disposed on the interior surface. In one or more embodiment, the interior surface includes a display and the laminate is disposed over the display. As used herein, vehicle includes automobiles, rolling stock, locomotive, boats, ships, and airplanes, helicopters, drones, space craft and the like.

[0062] In one or more reference examples, the laminate is positioned within a vehicle such that the first glass substrate faces the exterior of the vehicle (and the second glass substrate is adjacent the interior 710). In some embodiments, the second glass substrate of the laminate is in direct contact with the interior (i.e., the surface of the second glass substrate facing the interior is bare and is free of any coatings). In some embodiments, the first glass substrate of the laminate is in direct contact with the exterior (i.e., the surface of the glass substrate facing the exterior is bare and is free of any coatings).

[0063] In one or more reference examples, the laminate is configured to be an architectural glazing, and the unstrengthened glass substrate defines an outer substrate which faces an outside environment of the architectural structure and the internal strengthened glass substrate defines an inner substrate which faces an interior of the architectural structure.

[0064] In one or more reference examples, the laminate may have additional coating or layers applied to the exposed surfaces, including but not limited to tints, anti-reflection coatings, anti-glare coatings, scratch resistant coatings, etc. In one or more embodiments, the polymer interlayer can be modified to have one or more of the following properties: ultraviolet (UV) absorption, Infrared (IR) absorption, and IR reflection, acoustic control/dampening, adhesion promotion, and tint. The polymer interlayer can be modified by a suitable additive such as a dye, a pigment, dopants, etc. to impart the desired property.

[0065] In a reference example of a laminate, the unstrengthened glass substrate has a first thickness of 2.1 mm, 1.6 mm, or 1 mm and the strengthened glass substrate has a second thickness of 0.8 mm, 0.7 mm, 0.55 mm, 0.5 mm or 0.4 mm. The interlayer thickness is 0.76 mm.

[0066] The materials for the first glass substrate and the second glass substrate may be varied. As used herein, the term "glass substrate" includes an amorphous substrate, a crystalline substrate or a combination thereof. According to one or more embodiments, the materials for the unstrengthened glass substrate and the strengthened glass substrate may be SLG, alkali aluminosilicate glass, alkali containing borosilicate glass and/or alkali aluminoborosilicate glass or glass-ceramic (including Li_2O-Al_2O_3-SiO_2 system (i.e. LAS-System) glass ceramics, MgO-Al_2O_3-SiO_2 System (i.e. MAS-System) glass ceramics, glass ceramics including crystalline phases of any one or more of mullite, spinel, α-quartz, β-quartz solid solution, petalite, lithium disilicate, β-spodumene, nepheline, and alumina).

[0067] In one or more reference examples, the second glass substrate is strengthened to include a surface compressive stress (CS) that extends from a major surface to a depth of compression (DOC). The compressive stress regions are balanced by a central portion exhibiting a tensile stress. At the DOC, the stress crosses from a positive (compressive) stress to a negative (tensile) stress.

[0068] In one or more reference examples, the second glass substrate may be strengthened mechanically by utilizing a mismatch of the coefficient of thermal expansion between portions of the article to create a compressive stress region and a central region exhibiting a tensile stress. In some embodiments, the second glass substrate may be strengthened thermally by heating the glass to a temperature below the glass transition point and then rapidly quenching.

[0069] In one or more reference examples, the second glass substrate may be chemically strengthening by ion exchange. In the ion exchange process, ions at or near the surface of the second glass substrate are replaced by - or exchanged with - larger ions having the same valence or oxidation state. In those embodiments in which the second glass substrate comprises an alkali aluminosilicate glass, ions in the surface layer of the second glass substrate and the larger ions are monovalent alkali metal cations, such as Li^+, Na^+, K^+, Rb^+, and Cs^+. Alternatively, monovalent cations in the surface layer may be replaced with monovalent cations other than alkali metal cations, such as Ag^+ or the like. In such embodiments, the monovalent ions (or cations) exchanged into the second glass substrate generate a stress.

[0070] Ion exchange processes are typically carried out by immersing the second glass substrate in a molten salt bath (or two or more molten salt baths) containing the larger ions to be exchanged with the smaller ions in the second glass substrate. It should be noted that aqueous salt baths may also be utilized. In addition, the composition of the bath(s) may include more than one type of larger ion (e.g., Na+ and K+) or a single larger ion. It will be appreciated by those skilled in the art that parameters for the ion exchange process, including, but not limited to, bath composition and temperature, immersion time, the number of immersions of the glass substrate in a salt bath (or baths), use of multiple salt baths, additional steps such as annealing, washing, and the like, are generally determined by the composition of the second glass substrate (including the structure of the substrate and any crystalline phases present) and the desired DOC and CS of the second glass substrate that results from strengthening. Exemplary molten bath composition may include nitrates, sulfates, and chlorides of the larger alkali metal ion. Typical nitrates include KNO_3, $NaNO_3$, $LiNO_3$, $NaSO_4$ and combinations thereof. The temperature of the molten salt bath typically is in a range from about 380°C up to about 450°C, while immersion times range from about 15 minutes up to about 100 hours depending on second glass substrate thickness, bath temperature and glass (or monovalent ion) diffusivity. However, temperatures and immersion times different from those described above may also be used.

[0071] In one or more reference examples, the second glass substrate may be immersed in a molten salt bath of 100% $NaNO_3$, 100% KNO_3, or a combination of $NaNO_3$ and KNO_3 having a temperature from about 370 °C to about 480 °C. In some embodiments, the second glass substrate may be immersed in a molten mixed salt bath including from about 5% to about 90% KNO_3 and from about 10% to about 95% $NaNO_3$. In one or more embodiments, the second glass substrate may be immersed in a second bath, after immersion in a first bath. The first and second baths may have different compositions and/or temperatures from one another. The immersion times in the first and second baths may vary. For example, immersion in the first bath may be longer than the immersion in the second bath.

[0072] In one or more reference examples, the second glass substrate may be immersed in a molten, mixed salt bath including $NaNO_3$ and KNO_3 (e.g., 49%/51%, 50%/50%, 51%/49%) having a temperature less than about 420 °C (e.g., about 400 °C or about 380 °C). for less than about 5 hours, or even about 4 hours or less.

[0073] Ion exchange conditions can be tailored to provide a "spike" or to increase the slope of the stress profile at or near the surface of the resulting second glass substrate. The spike may result in a greater surface CS value. This spike can be achieved by single bath or multiple baths, with the bath(s) having a single composition or mixed composition, due to the unique properties of the glass compositions used in the second glass substrate described herein.

[0074] In one or more reference examples, where more than one monovalent ion is exchanged into the second glass substrate, the different monovalent ions may exchange to different depths within the second glass substrate (and generate different magnitudes stresses within the glass substrate at different depths). The resulting relative depths of the stress-generating ions can be determined and cause different characteristics of the stress profile.

[0075] CS is measured using those means known in the art, such as by surface stress meter (FSM) using commercially available instruments such as the FSM-6000, manufactured by Orihara Industrial Co., Ltd. (Japan). Surface stress measurements rely upon the accurate measurement of the stress optical coefficient (SOC), which is related to the birefringence of the glass. SOC in turn is measured by those methods that are known in the art, such as fiber and four point bend methods, both of which are described in ASTM standard C770-98 (2013), entitled "Standard Test Method for Measurement of Glass Stress-Optical Coefficient," the contents of which are incorporated herein by reference in their entirety, and a bulk cylinder method. As used herein CS may be the "maximum compressive stress" which is the highest compressive stress value measured within the compressive stress layer. In some embodiments, the maximum compressive stress is located at the surface of the glass substrate. In other embodiments, the maximum compressive stress may occur at a depth below the surface, giving the compressive profile the appearance of a "buried peak."

[0076] DOC may be measured by FSM or by a scattered light polariscope (SCALP) (such as the SCALP-04 scattered light polariscope available from Glasstress Ltd., located in Tallinn Estonia), depending on the strengthening method and conditions. When the second glass substrate is chemically strengthened by an ion exchange treatment, FSM or SCALP may be used depending on which ion is exchanged into the glass substrate. Where the stress in the second glass substrate is generated by exchanging potassium ions into the glass substrate, FSM is used to measure DOC. Where the stress is generated by exchanging sodium ions into the second glass substrate, SCALP is used to measure DOC. Where the stress in the second glass substrate is generated by exchanging both potassium and sodium ions into the glass, the DOC is measured by SCALP, since it is believed the exchange depth of sodium indicates the DOC and the exchange depth of potassium ions indicates a change in the magnitude of the compressive stress (but not the change in stress from compressive to tensile); the exchange depth of potassium ions in such glass a substrates is measured by FSM.

[0077] In one or more reference examples, the second glass substrate maybe strengthened to exhibit a DOC that is described a fraction of the thickness t of the second glass substrate (as described herein). For example, in one or more embodiments, the DOC may be equal to or greater than about 0.1t, equal to or greater than about 0.11t, equal to or greater than about 0.12t, equal to or greater than about 0.13t, equal to or greater than about 0.14t, equal to or greater than about 0.15t, equal to or greater than about 0.16t, equal to or greater than about 0.17t, equal to or greater than about 0.18t, equal to or greater than about 0.19t, equal to or greater than about 0.2t, equal to or greater than about 0.21t. In some embodiments, The DOC may be in a range from about 0.08t to about 0.25t, from about 0.09t to about 0.25t, from about 0.18t to about 0.25t, from about 0.11t to about 0.25t, from about 0.12t to about 0.25t, from about 0.13t to about 0.25t, from about 0.14t to about 0.25t, from about 0.15t to about 0.25t, from about 0.08t to about 0.24t, from about 0.08t to about 0.23t, from about 0.08t to about 0.22t, from about 0.08t to about 0.21t, from about 0.08t to about 0.2t, from about 0.08t to about 0.19t, from about 0.08t to about 0.18t, from about 0.08t to about 0.17t, from about 0.08t to about 0.16t, or from about 0.08t to about 0.15t. In some instances, the DOC may be about 20 μm or less. In one or more embodiments, the DOC may be about 40 μm or greater (e.g., from about 40 μm to about 300 μm, from about 50 μm to about 300 μm, from about 60 μm to about 300 μm, from about 70 μm to about 300 μm, from about 80 μm to about 300 μm, from about 90 μm to about 300 μm, from about 100 μm to about 300 μm, from about 110 μm to about 300 μm, from about 120 μm to about 300 μm, from about 140 μm to about 300 μm, from about 150 μm to about 300 μm, from about 40 μm to about 290 μm, from about 40 μm to about 280 μm, from about 40 μm to about 260 μm, from about 40 μm to about 250 μm, from about 40 μm to about 240 μm, from about 40 μm to about 230 μm, from about 40 μm to about 220 μm, from about 40 μm to about 210 μm, from about 40 μm to about 200 μm, from about 40 μm to about 180 μm, from about 40 μm to about 160 μm, from about 40 μm to about 150 μm, from about 40 μm to about 140 μm, from about 40 μm to about 130 μm, from about 40 μm to about 120 μm, from about 40 μm to about 110 μm, or from about 40 μm to about 100 μm.

[0078] In one or more reference examples, the strengthened second glass substrate may have a CS (which may be found at the surface of the second glass substrate) of about 400 MPa or greater, about 500 MPa or greater, about 600 MPa or greater, about 700 MPa or greater, about 800 MPa or greater, about 900 MPa or greater, about 930 MPa or greater, about 1000 MPa or greater, or about 1050 MPa or greater.

[0079] In one or more reference examples, the strengthened second glass substrate may have a maximum tensile stress or central tension (CT) of about 20 MPa or greater, about 30 MPa or greater, about 40 MPa or greater, about 45 MPa or greater, about 50 MPa or greater, about 60 MPa or greater, about 70 MPa or greater, about 75 MPa or greater, about 80 MPa or greater, or about 85 MPa or greater. In some embodiments, the maximum tensile stress or central tension (CT) may be in a range from about 40 MPa to about 100 MPa.

[0080] Examples of glasses that may be used in the second glass substrate may include alkali alumino silicate glass compositions or alkali aluminoborosilicate glass compositions, though other glass compositions are contemplated. Such glass compositions may be characterized as ion exchangeable. One example glass composition comprises SiO_2, B_2O_3 and Na_2O, where (SiO_2 + B_2O_3) ≥ 66 mol. %, and Na_2O ≥ 9 mol. %. In an embodiment, the glass composition includes at least 6 wt.% aluminum oxide. In a further embodiment, the substrate includes a glass composition with one or more alkaline earth oxides, such that a content of alkaline earth oxides is at least 5 wt.%. Suitable glass compositions, in some embodiments, further comprise at least one of K_2O, MgO, and CaO. In a particular embodiment, the glass compositions used in the substrate can comprise 61-75 mol.% SiO_2; 7-15 mol.% Al_2O_3; 0-12 mol.% B_2O_3; 9-21 mol.% Na_2O; 0-4 mol.% K_2O; 0-7 mol.% MgO; and 0-3 mol.% CaO.

[0081] A further example glass composition suitable for the substrate comprises: 60-70 mol.% SiO_2; 6-14 mol.% Al_2O_3; 0-15 mol.% B_2O_3; 0-15 mol.% Li_2O; 0-20 mol.% Na_2O; 0-10 mol.% K_2O; 0-8 mol.% MgO; 0-10 mol.% CaO; 0-5 mol.% ZrO_2; 0-1 mol.% SnO_2; 0-1 mol.% CeO_2; less than 50 ppm As_2O_3; and less than 50 ppm Sb_2O_3; where 12 mol.% ≤ (Li_2O + Na_2O + K_2O) ≤ 20 mol.% and 0 mol.% ≤ (MgO + CaO) ≤ 10 mol.%.

[0082] A still further example glass composition suitable for the substrate comprises: 63.5-66.5 mol.% SiO_2; 8-12 mol.% Al_2O_3; 0-3 mol.% B_2O_3; 0-5 mol.% Li_2O; 8-18 mol.% Na_2O; 0-5 mol.% K_2O; 1-7 mol.% MgO; 0-2.5 mol.% CaO; 0-3 mol.% ZrO_2; 0.05-0.25 mol.% SnO_2; 0.05-0.5 mol.% CeO_2; less than 50 ppm As_2O_3; and less than 50 ppm Sb_2O_3; where 14 mol.% ≤ (Li_2O + Na_2O + K_2O) ≤ 18 mol.% and 2 mol.% ≤ (MgO + CaO) ≤ 7 mol.%.

[0083] In a particular reference example, an alkali aluminosilicate glass composition suitable for the second glass substrate comprises alumina, at least one alkali metal and, in some embodiments, greater than 50 mol.% SiO_2, in other embodiments at least 58 mol.% SiO_2, and in still other embodiments at least 60 mol.% SiO_2, wherein the ratio $((Al_2O_3 + B_2O_3)/\Sigma \text{ modifiers})>1$, where in the ratio the components are expressed in mol.% and the modifiers are alkali metal oxides. This glass composition, in particular embodiments, comprises: 58-72 mol.% SiO_2; 9-17 mol.% Al_2O_3; 2-12 mol.% B_2O_3; 8-16 mol.% Na_2O; and 0-4 mol.% K_2O, wherein the ratio$((Al_2O_3 + B_2O_3)/\Sigma\text{modifiers})>1$.

[0084] In still another reference example, the second glass substrate may include an alkali aluminosilicate glass composition comprising: 64-68 mol.% SiO_2; 12-16 mol.% Na_2O; 8-12 mol.% Al_2O_3; 0-3 mol.% B_2O_3; 2-5 mol.% K_2O; 4-6 mol.% MgO; and 0-5 mol.% CaO, wherein: 66 mol.% ≤ SiO_2 + B_2O_3 + CaO ≤ 69 mol.%; Na_2O + K_2O + B_2O_3 + MgO + CaO + SrO > 10 mol.%; 5 mol.% ≤ MgO + CaO + SrO ≤ 8 mol.%; (Na_2O + B_2O_3) - Al_2O_3 ≤ 2 mol.%; 2 mol.% ≤ Na_2O - Al_2O_3 ≤ 6 mol.%; and 4 mol.% ≤ (Na_2O + K_2O) - Al_2O_3 ≤ 10 mol.%.

[0085] In an alternative reference example, the second glass substrate may comprise an alkali aluminosilicate glass composition comprising: 2 mol% or more of Al_2O_3 and/or ZrO_2, or 4 mol% or more of Al_2O_3 and/or ZrO_2.

[0086] In some embodiments, the compositions used for a second glass substrate may be batched with 0-2 mol. % of at least one fining agent selected from a group that includes Na_2SO_4, NaCl, NaF, NaBr, K_2SO_4, KCl, KF, KBr, and SnO_2.

[0087] Another reference exampleof the present disclosure relates to a method of manufacturing a laminate comprising arranging an unstrengthened glass substrate (i.e., the first glass substrate), an interlayer, and a strengthened glass substrate (i.e., the second glass substrate) in a stack. In various embodiments, the laminate may be formed by placing the glass substrates and interlayer in a pre-press to tack the interlayer to the strengthened glass substrates. Tacking can include expelling most of the air from the interfaces and partially bonding the interlayer to the glass substrates.

[0088] During a lamination process, the interlayer may be heated to a temperature effective to soften the interlayer, which promotes a conformal mating of the interlayer to respective surfaces of the glass substrates. For PVB, a lamination temperature can be about 140°C. The mobile polymer chains within the interlayer material develop bonds with the substrate surfaces, which promote adhesion. Elevated temperatures also accelerate the diffusion of residual air and/or moisture from the glass-polymer interface. The heating can be performed with the glass substrate(s) in contact with the interlayer under pressure. In various embodiments, the application of pressure both promotes flow of the interlayer material, and suppresses bubble formation that otherwise could be induced by the combined vapor pressure of water and air trapped at the interfaces. In various embodiments, a forming process can occur at or just above the softening temperature of the interlayer material (e.g., about 100 °C to about 120 °C), that is, at a temperature less than the softening temperature of the respective strengthened glass substrate(s).

[0089] In one or more reference examples, the heat and pressure can be simultaneously applied to the assembly in an autoclave. In various embodiments, the stack of an external chemically strengthened glass substrate, an interlayer, and an internal chemically strengthened glass substrate may be placed within a vacuum bag or a vacuum ring for processing. In various embodiments, the stack and vacuum bag or vacuum ring may be placed with the autoclave.

EXAMPLES

[0090] The following non-limiting examples demonstrate principles according to one or more embodiments of the disclosure.

Example 1

[0091] Studies were conducted to improve the edge strength of SLG substrates by varying edge grinding conditions. SLG substrates having a thickness of about 2.1 mm were subjected to a known edge grinding process using a standard 220 mesh bronze bond grind wheel. The standard grind wheel was replaced with a 400 mesh bronze bond grind wheel, and all other process parameters for edge grinding remained constant. The edge grinding process parameters included the following: Substrate feed rate = 1.0 m/min, grind wheel diameter = 50.8 mm, grind wheel rotation speed = 10,000 rpm, depth of cut per pass = 127 μm, number of passes = 3 passes, coolant flow rate > 10 gal/min in flood coolant form. The SLG substrates with an edge-finished edge were combined with a chemically strengthened glass substrate having a thickness of 0.7 mm, and an intervening interlayer. The mechanical edge strength of the laminate including a SLG substrate having an edge that was edge finished using the 400 mesh bronze grind wheel exhibited an edge strength of 26.9 pounds of force, as measured by the three point bend test.

Example 2

[0092] A series of experiments was conducted to determine the effect of abrasive particle composition on SLG edge strength. Examples A-M represent the different abrasive particle compositions evaluated. In Table 1 below, "MD" refers to metal bond diamond abrasive. "RD" refers to resin bond diamond abrasive. The abrasives are referred to in terms of primary (abbreviated "Prim."), secondary (abbreviated "Sec.") and tertiary (abbreviated "Tert." Abrasives. Various volume percentages and various sizes were combined to form metal bond grinding wheel as shown in Table 1 below.

TABLE 1

Ex.	Prim. Type	Prim. Size (microns)	Prim. Vol.%	Sec. Type	Sec. Size (microns)	Sec. Vol.%	Tert. Type	Tert. Size (microns)	Tert. Vol.%
A	MD	40-50	24.31	RD	30-40	6.94	None	N/A	0
B	MD	30-40	12.64	MD	20-30	3.61	MD	1-10	1.25
C	RD	40-50	12.64	RD	30-40	3.61	MD	1-10	1.25
D	MD	30-40	24.31	MD	20-30	6.94	None	N/A	0
E	RD	40-50	12.64	MD	30-40	3.61	None	N/A	0
F	MD	40-50	24.31	RD	30-40	6.94	MD	1-10	1.25
G	MD	40-50	12.64	MD	30-40	3.61	MD	1-10	1.25
H	RD	30-40	24.31	MD	20-30	6.94	MD	1-10	1.25
I	RD	40-50	24.31	MD	30-40	6.94	None	N/A	0
J	RD	30-40	24.31	RD	20-30	6.94	MD	1-10	1.25
K	MD	30-40	12.64	RD	20-30	3.61	None	N/A	0
L	MD (comp.)	40-50	31.25	None	N/A	0	None	N/A	0
M	RD (comp).	40-50	31.25	None	N/A	0	None	N/A	0

[0093] Examples L-M in Table 1 are comparative examples, which were 400 mesh wheels made with each metal bond and resin bond diamond abrasives. The edges of 2.1 mm thick SLG substrates were edge finished with each of Examples A-M. The edge strength of the substrates edge-finished using the abrasive particle compositions Table 1 was measured and compared to the edge strength of 2.1 mm thick SLG substrates that were edge-finished using a known standard 220 mesh grind bronze-bonded diamond grind wheels. The edge strength was measured using a four point bend test (ASTM C 158-02). The edge strength wasWeibull plotted (95% Confidence Interval). The Weibull Plot is shown in FIG. 4.

[0094] The analysis of the four point bend data using the Weibull distribution showed that the standard 220 mesh grind wheels provided an average edge strength of 84.4 MPa, while the 400 mesh grind wheel (comparative example) provided an average edge strength of 97.3 MPa, which was an improvement of 15.3%. Grind wheels made with 40-50 micron metal bond diamond abrasive in an iron bonded wheel resulted in an average edge strength of 105.9 MPa, a 25.5% improvement, and grind wheels made with 40-50 micron resin bond diamond abrasive in an iron bonded wheel resulted in an edge strength of 112.7 MPa, a 33.5% improvement. Unexpectedly, a resin bond diamond abrasive, typically placed in a resin bonded wheel, performed very well and improved the average edge strength of SLG substrates ground with a metal bond wheel, compared with the other grind wheels.

[0095] Statistical analysis was performed on the Plackett-Burman experimental matrix for grind wheel composition using mechanical edge strength as the response variable to evaluate the grind wheel composition Design of Experiments 4-point bend mechanical edge strength data , and it was determined that two factors impacted mechanical edge strength, primary abrasive particle size and the presence of tertiary abrasive. Unexpectedly, it was determined that the addition of a small quantity (1.25 vol. %) of very small (1-10 μm particle size) metal bond diamond abrasive into the iron bond material significantly increased the resulting mechanical edge strength of the substrates ground with wheels in which this composition tactic was employed. The results of this data should not be construed as limited to an abrasive type, quantity or particle size. According to one or more embodiments, the presence of a primary abrasive with a primary particle size and a secondary abrasive with a secondary particle size less than or equal to the primary particle size in a grind wheel improves edge strength when compared to grind wheel data with only single particle size. According to one or more embodiments, results can further be improved by the presence of a tertiary abrasive having a tertiary particle size less than the secondary particle size. In one or more embodiments, the tertiary abrasive particles act as a bond stiffener.

[0096] FIG. 5 shows a Plackett-Burman plot demonstrating the added benefit of blending different sized abrasives in the composition of grind wheels designed to edge finish brittle materials such as SLG. In FIG. 5, four point bend mechanical edge strength data is plotted for two blended composition wheels and compared to the metal bond diamond and resin bond diamond 400 mesh controls. As shown in FIG. 5 and in all of the intermediate wheel compositions tested in the Plackett-Burman design of experiments, blended abrasive wheels with primary particles and secondary particles out-performed comparative examples with only a single sized abrasive particle. In this specific experiment, size blending was kept constant at 70 volume percent primary size abrasive and 30 volume percent secondary size abrasive, however, other blend volumes are within the scope of this disclosure. The contribution of the tertiary diamond abrasive was not considered when determining volume fractions in size blended wheels.

Claims

1. A grinding wheel (410) comprising:

a metal bond matrix structure (412);
a plurality of primary abrasive diamond particles (401) within the matrix structure (412) and having a primary particle size; and
a plurality of secondary abrasive particles (402) within the matrix structure (412) and having a secondary particle size that is less than or equal to the primary particle size, wherein one of the primary abrasive diamond particles (401) and secondary abrasive particles (402) comprises resin bond diamond particles, **characterized in that**, either the plurality of primary abrasive diamond particles (401) comprises resin bond diamond particles and the plurality of secondary abrasive particles (402) comprises metal bond diamond particles, or
the plurality of secondary abrasive particles (402) comprises resin bond diamond particles and the plurality of primary abrasive diamond particles (401) comprises metal bond diamond particles.

2. The grinding wheel (410) of claim 1, wherein the grinding wheel (410) comprises a grinding wheel volume, wherein the metal bond matrix structure (412) comprises from 60 volume % to 90 volume % of the grinding wheel volume, and wherein the plurality of primary abrasive diamond particles (401) and the plurality of secondary abrasive particles (402) comprises from 10 volume % to 40 volume % of the grinding wheel volume.

3. The grinding wheel (410) of any one of the preceding claims, wherein the metal bond matrix structure (412) comprises iron.

4. The grinding wheel (410) of any one of the preceding claims, wherein the primary abrasive diamond particles (401) and second abrasive particles (402) comprise a total abrasive particle volume, wherein the primary abrasive particles (401) comprise from 51% to 97% of the total abrasive particle volume, and wherein the secondary abrasive particles (402) comprise from 2% to 48% of the total abrasive particle volume.

5. The grinding wheel (410) of any one of the preceding claims, further comprising a plurality of tertiary diamond abrasive particles within the metal bond matrix structure, the plurality of tertiary diamond abrasive particles having a tertiary particle size less than or equal to the secondary particle size.

6. The grinding wheel (410) of claim 5, wherein the primary particle size is in a range from 30 microns to 40 microns, the secondary particle size in a range from 20 microns to 30 microns, and the tertiary particle size is in a range from 1 micron to 10 microns.

7. The grinding wheel (410) of claim 5, wherein the primary particle size is in a range from 50 microns to 60 microns, the secondary particle size in a range from 40 microns to 50 microns, and the tertiary particle size is in a range from 4 microns to 8 microns.

8. The grinding wheel (410) of claim 1, wherein the primary particle size is in a range from 30 microns to 40 microns and the secondary particle size in a range from 15 microns to 30 microns.

9. The grinding wheel (410) of claim 8, further comprising tertiary diamond abrasive particles within the metal bond matrix structure and having a tertiary particle size less than the secondary particle size.

10. The grinding wheel (410) of claim 9, wherein the tertiary particle size is in a range from 1 to 10 microns.

Patentansprüche

1. Schleifscheibe (410), aufweisend:

   eine Metallbindungs-Matrixstruktur (412);
   eine Vielzahl von primären Diamant-Schleifpartikeln (401) innerhalb der Matrixstruktur (412), die eine Primärpartikelgröße haben; und
   eine Vielzahl von sekundären Schleifpartikeln (402) innerhalb der Matrixstruktur (412), die eine Sekundärpartikelgröße haben, die kleiner als oder so groß wie die Primärpartikelgröße ist, wobei die primären Diamant-Schleifpartikel (401) oder sekundären Schleifpartikel (402) Kunstharzbindungs-Diamantpartikel aufweisen, **dadurch gekennzeichnet, dass**
   entweder die Vielzahl der primären Diamant-Schleifpartikel (401) Kunstharzbindungs-Diamantpartikel aufweist und die Vielzahl der sekundären Schleifpartikel (402) Metallbindungs-Diamantpartikel aufweist, oder
   die Vielzahl der sekundären Schleifpartikel (402) Kunstharzbindungs-Diamantpartikel aufweist und die Vielzahl der primären Diamant-Schleifpartikel (401) Metallbindungs-Diamantpartikel aufweist.

2. Schleifscheibe (410) nach Anspruch 1, wobei die Schleifscheibe (410) ein Schleifscheibenvolumen aufweist, wobei die Metallbindungs-Matrixstruktur (412) 60 Volumenprozent bis 90 Volumenprozent des Schleifscheibenvolumens ausmacht, und wobei die Vielzahl der primären Diamant-Schleifpartikel (401) und die Vielzahl der sekundären Schleifpartikel (402) 10 Volumenprozent bis 40 Volumenprozent des Schleifscheibenvolumens ausmachen.

3. Schleifscheibe (410) nach einem der vorhergehenden Ansprüche, wobei die Metallbindungs-Matrixstruktur (412) Eisen aufweist.

4. Schleifscheibe (410) nach einem der vorhergehenden Ansprüche, wobei die primären Diamant-Schleifpartikel (401) und die sekundären Schleifpartikel (402) ein Gesamt-Schleifpartikelvolumen aufweisen, wobei die primären Schleifpartikel (401) 51% bis 97% des Gesamt-Schleifpartikelvolumens und die sekundären Schleifpartikel (402) 2% bis 48% des Gesamt-Schleifpartikelvolumens ausmachen.

5. Schleifscheibe (410) nach einem der vorhergehenden Ansprüche, darüber hinaus eine Vielzahl von tertiären Diamant-Schleifpartikeln innerhalb der Metallbindungs-Matrixstruktur aufweisend, wobei die Vielzahl der tertiären Diamant-Schleifpartikel eine Tertiärpartikelgröße haben, die kleiner als oder so groß wie die Sekundärpartikelgröße ist.

6. Schleifscheibe (410) nach Anspruch 5, wobei die Primärpartikelgröße in einem Bereich von 30 Mikrometer bis 40 Mikrometer, die Sekundärpartikelgröße in einem Bereich von 20 Mikrometer bis 30 Mikrometer und die Tertiärpartikelgröße in einem Bereich von 1 Mikrometer bis 10 Mikrometer liegt.

7. Schleifscheibe (410) nach Anspruch 5, wobei die Primärpartikelgröße in einem Bereich von 50 Mikrometer bis 60 Mikrometer, die Sekundärpartikelgröße in einem Bereich von 40 Mikrometer bis 50 Mikrometer und die Tertiärpartikelgröße in einem Bereich von 4 Mikrometer bis 8 Mikrometer liegt.

8. Schleifscheibe (410) nach Anspruch 1, wobei die Primärpartikelgröße in einem Bereich von 30 Mikrometer bis 40 Mikrometer und die Sekundärpartikelgröße in einem Bereich von 15 Mikrometer bis 30 Mikrometer liegt.

9. Schleifscheibe (410) nach Anspruch 8, darüber hinaus tertiäre Diamant-Schleifpartikel innerhalb der Metallbindungs-Matrixstruktur aufweisend, die eine Tertiärpartikelgröße haben, die kleiner als die Sekundärpartikelgröße ist.

10. Schleifscheibe (410) nach Anspruch 9, wobei die Tertiärpartikelgröße in einem Bereich von 1 bis 10 Mikrometer liegt.

Revendications

1. Roue de meulage (410) comprenant :

une structure de matrice de liaison par métal (412) ;
une pluralité de particules de diamant abrasives primaires (401) à l'intérieur de la structure de matrice (412) et ayant une taille de particules primaires ; et
une pluralité de particules abrasives secondaires (402) à l'intérieur de la structure de matrice (412) et ayant une taille de particules secondaires inférieure ou égale à la taille de particules primaires, sachant que soit les particules de diamant abrasives primaires (401) soit les particules abrasives secondaires (402) comprennent des particules de diamant à liaison par résine, **caractérisée en ce que** soit la pluralité de particules de diamant abrasives primaires (401) comprend des particules de diamant à liaison par résine et la pluralité de particules abrasives secondaires (402) comprend des particules de diamant à liaison par métal ; soit
la pluralité de particules abrasives secondaires (402) comprend des particules de diamant à liaison par résine et la pluralité de particules de diamant abrasives primaires (401) comprend des particules de diamant à liaison par métal.

2. La roue de meulage (410) de la revendication 1, sachant que la roue de meulage (410) comprend un volume de roue de meulage, sachant que la structure de matrice de liaison par métal (412) comprend de 60 % en volume à 90 % en volume du volume de roue de meulage, et sachant que la pluralité de particules de diamant abrasives primaires (401) et la pluralité de particules abrasives secondaires (402) comprennent de 10 % en volume à 40 % en volume du volume de roue de meulage.

3. La roue de meulage (410) de l'une quelconque des revendications précédentes, sachant que la structure de matrice de liaison par métal (412) comprend du fer.

4. La roue de meulage (410) de l'une quelconque des revendications précédentes, sachant que les particules de diamant abrasives primaires (401) et les particules abrasives secondaires (402) comprennent un volume de particules abrasives total, sachant que les particules abrasives primaires (401) comprennent de 51 % à 97 % du volume de particules abrasives total, et sachant que les particules abrasives secondaires (402) comprennent de 2 % à 48 % du volume de particules abrasives total.

5. La roue de meulage (410) de l'une quelconque des revendications précédentes, comprenant en outre une pluralité de particules abrasives de diamant tertiaires à l'intérieur de la structure de matrice de liaison par métal, la pluralité de particules abrasives de diamant tertiaires ayant une taille de particules tertiaires inférieure ou égale à la taille de particules secondaires.

6. La roue de meulage (410) de la revendication 5, sachant que la taille de particules primaires est comprise dans une plage de 30 microns à 40 microns, la taille de particules secondaires est comprise dans une plage de 20 microns à 30 microns, et la taille de particules tertiaires est comprise dans une plage de 1 micron à 10 microns.

7. La roue de meulage (410) de la revendication 5, sachant que la taille de particules primaires est comprise dans une plage de 50 microns à 60 microns, la taille de particules secondaires est comprise dans une plage de 40 microns à 50 microns, et la taille de particules tertiaires est comprise dans une plage de 4 microns à 8 microns.

8. La roue de meulage (410) de la revendication 1, sachant que la taille de particules primaires est comprise dans une plage de 30 microns à 40 microns et la taille de particules secondaires est comprise dans une plage de 15 microns à 30 microns.

9. La roue de meulage (410) de la revendication 8, comprenant en outre des particules abrasives de diamant tertiaires à l'intérieur de la structure de matrice de liaison par métal et ayant une taille de particules tertiaires inférieure à la taille de particules secondaires.

10. La roue de meulage (410) de la revendication 9, sachant que la taille de particules tertiaires est comprise dans une plage de 1 à 10 microns.

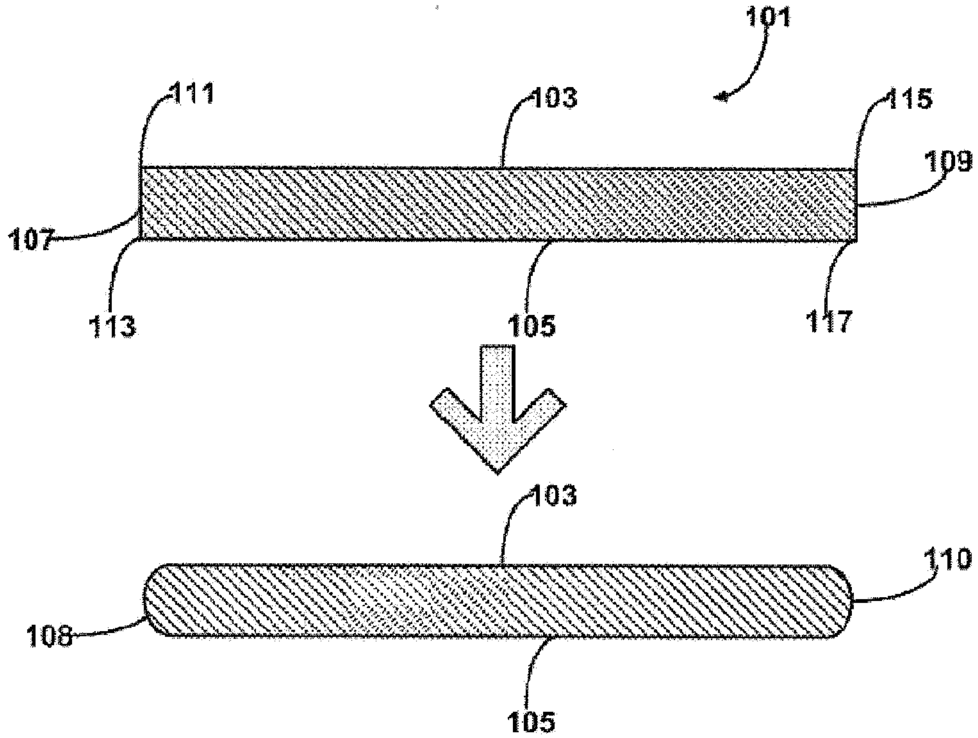


Fig. 1

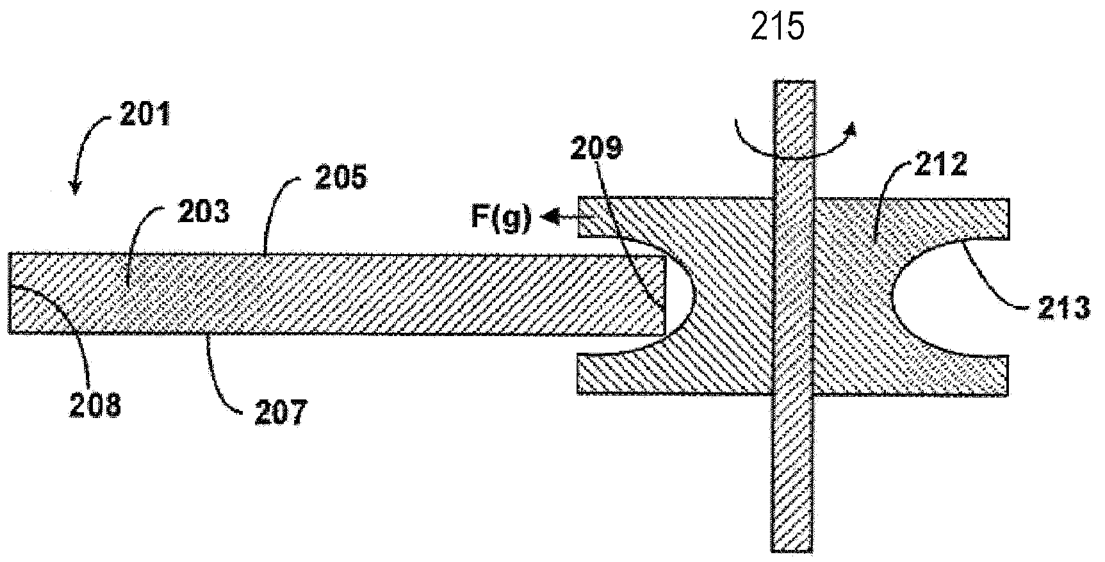


Fig. 2

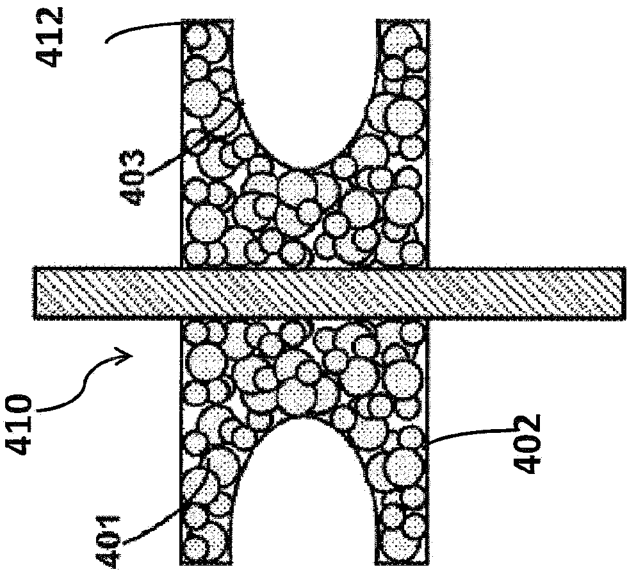


Fig. 3

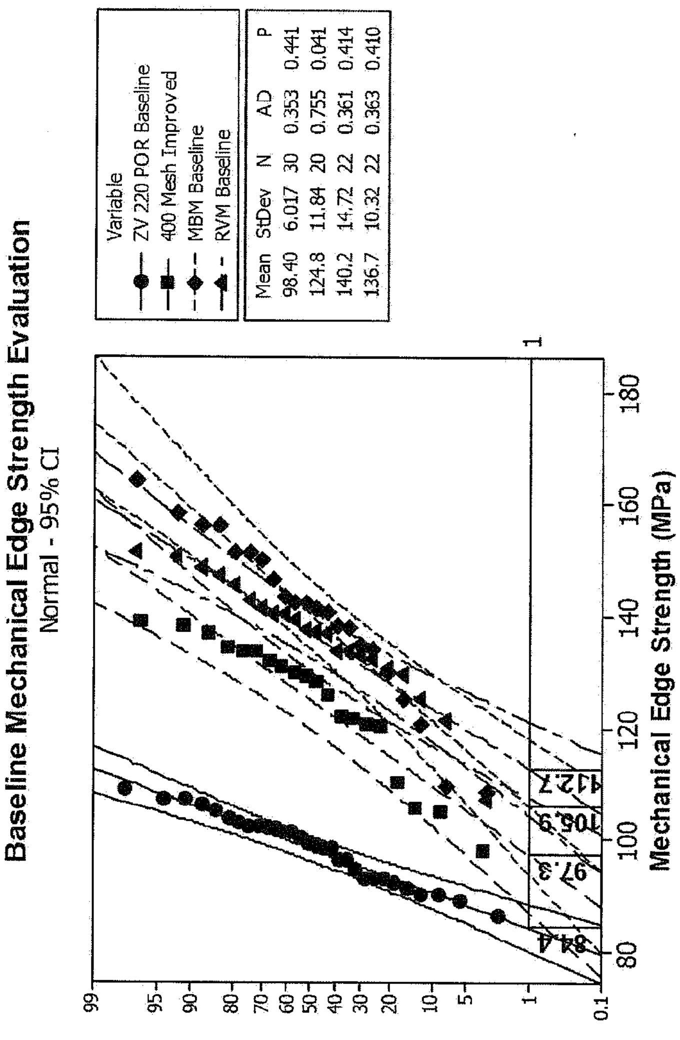

Baseline Mechanical Edge Strength Evaluation
Normal - 95% CI
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
80
100
120
140
160
180
Mechanical Edge Strength (MPa)
84.4
97.3
106.9
112.7
1
Variable
ZV 220 POR Baseline
400 Mesh Improved
MBM Baseline
RVM Baseline
Mean StDev N AD P
98.40 6.017 30 0.353 0.441
124.8 11.84 20 0.755 0.041
140.2 14.72 22 0.361 0.414
136.7 10.32 22 0.363 0.410

Fig. 4

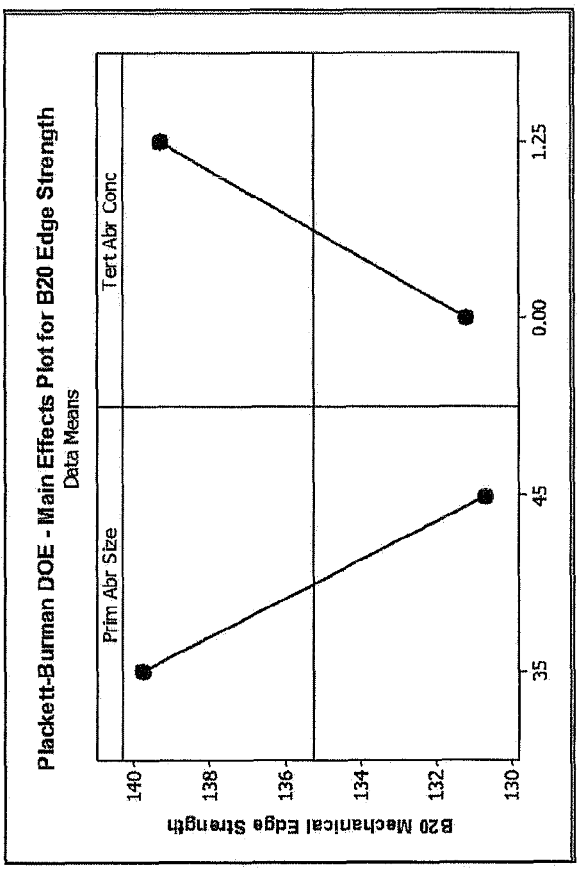

Plackett-Burman DOE - Main Effects Plot for B20 Edge Strength
Data Means
Prim Abr Size
Tert Abr Conc
B20 Mechanical Edge Strength
140
138
136
134
132
130
35
45
0.00
1.25

Fig. 5

FIGURE 6

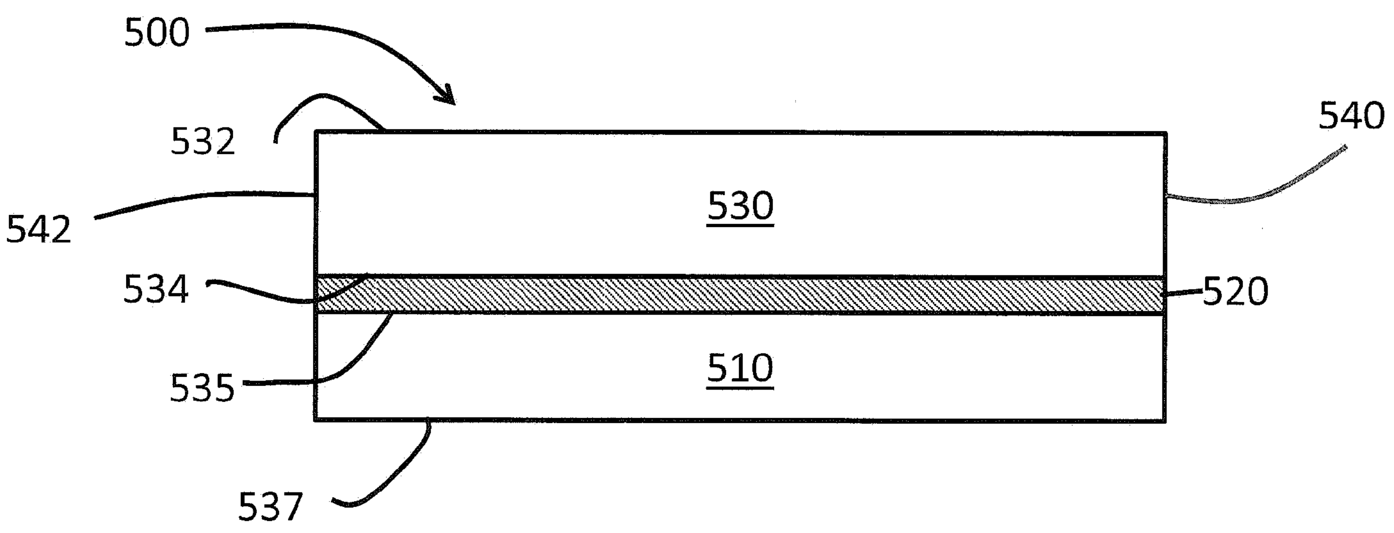


FIGURE 7

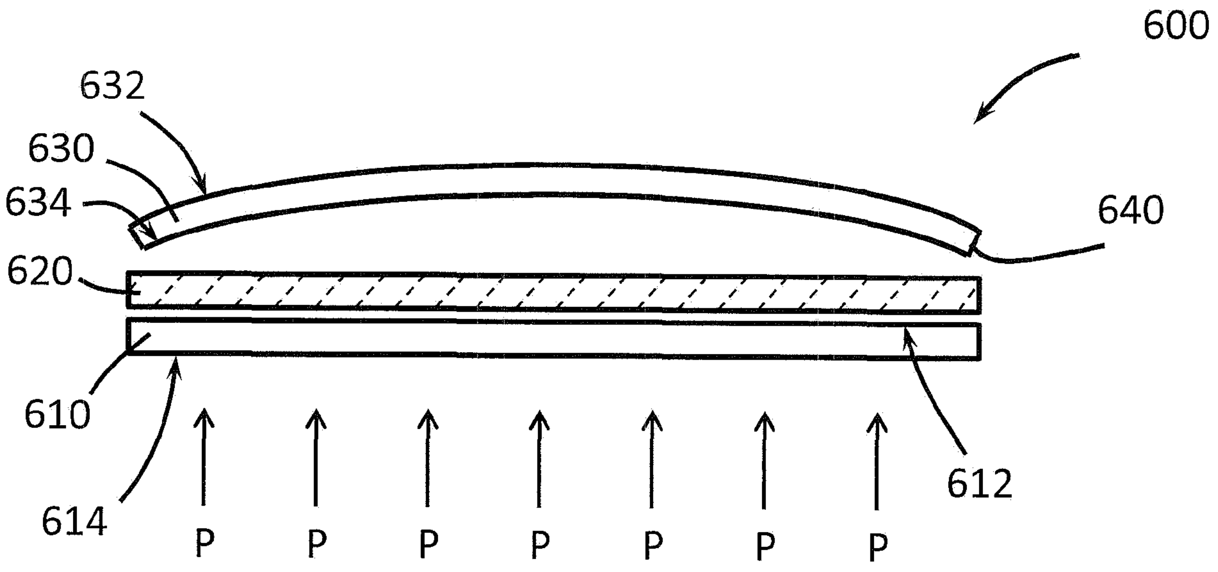


FIGURE 8

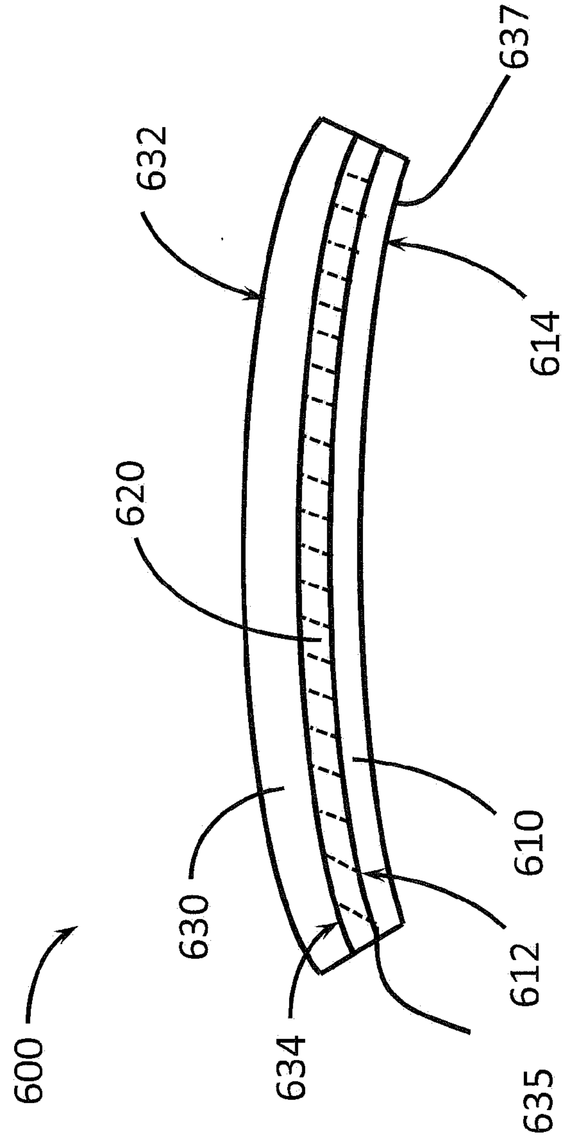
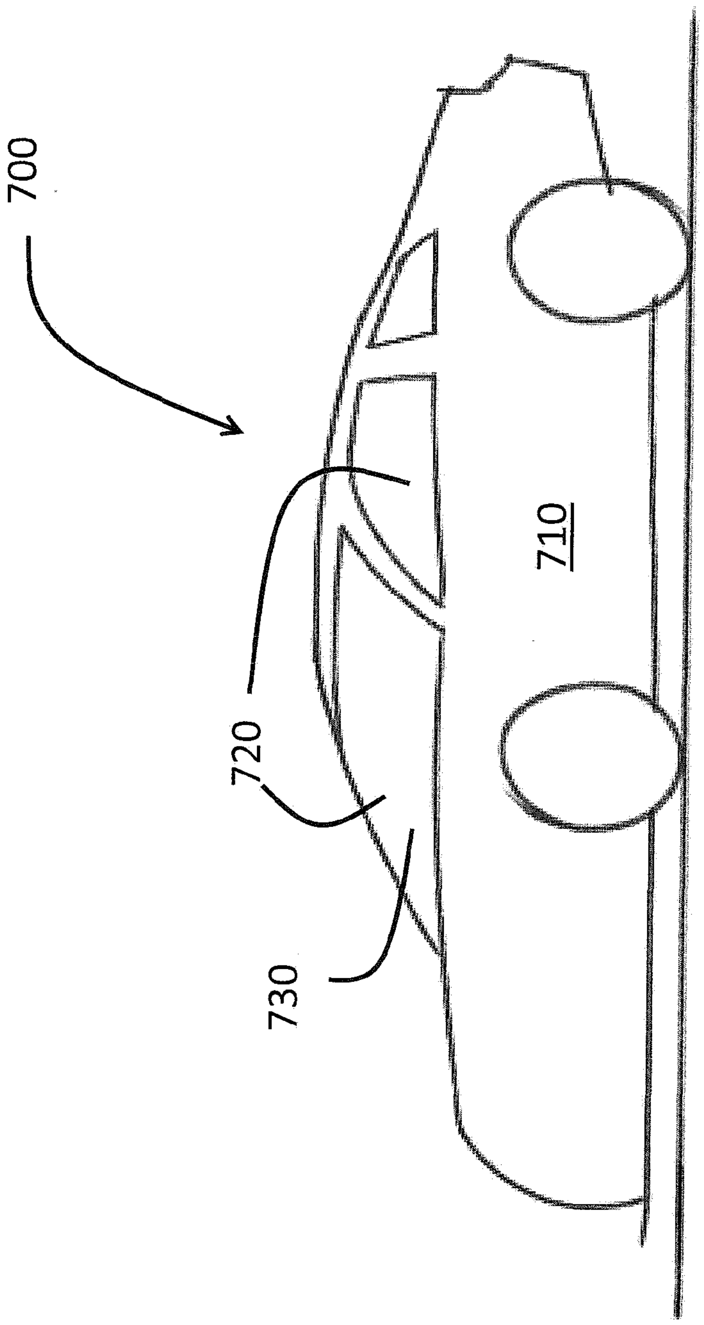


FIGURE 9



REFERENCES CITED IN THE DESCRIPTION

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- US 3925035 A **[0006]**

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- **MARINESCU, I.** *Tribology of Abrasive Machining Processes,* 2012 **[0012]**
- **TIMOTHY F. DUMM.** Fracture Characteristics of Superabrasive Diamond and CBN Micron Powders. *1st International Particle Technology Forum,* 17 August 1994 **[0012]**
- Standard Test Method for Measurement of Glass Stress-Optical Coefficient. *ASTM standard C770-98,* 2013 **[0075]**