DIRECT PLATED TOOLS

BACKGROUND

Field of the Disclosure

[0001] The following is directed generally to direct plated tools, and more particularly to abrasive articles having a plurality of metal bonding layers or regions.

Description of the Related Art

[0002] A variety of abrasive tools have been developed over the past century for various industries for the general function of removing material from a workpiece, including for example, sawing, drilling, polishing, cleaning, carving, and grinding. Some examples of such abrasive tools include direct plated tools that include a metal bonding layer or region directly plated to a substrate, typically a metal (e.g. steel) substrate.

[0003] The industry continues to demand improved materials, particularly for applications of abrasive grinding.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

[0005] FIG. 1 includes a flow chart providing a process for forming an abrasive article in accordance with an embodiment.

[0006] FIG. 2 includes an illustration of a side plan view of a portion of an abrasive article in accordance with an embodiment.

[0007] FIG. 3 includes a graph showing performance improvements of samples made in accordance to embodiments herein compared to a comparative sample.

[0008] The use of the same reference symbols in different drawings indicates similar or identical items.

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DETAILED DESCRIPTION

[0009] The following is generally directed to abrasive articles having abrasive particles adhered to a substrate by one or more bonding regions or regions. The one or more bonding regions can be formed through various techniques, including for example, a deposition process. Some suitable deposition processes can include, printing, spraying, dip coating, die coating, plating (e.g., electrolyte or electroless), and a combination thereof. In accordance with one particular embodiment, the bonding regions can be formed by a plating process. For at least one particular embodiment, the plating process can be an electrolyte plating (electroplating) process. In another embodiment, the plating process can include an electroless plating process. In one aspect, the abrasive particles can be adhered to the substrate through an electroplating process. In another aspect, the abrasive particles can be further bonded in place on the substrate through an electroless plating process that forms an electroless layer or region over one or more electroplated regions or regions. In a particular aspect, the abrasive particles can be bonded to the substrate through one or more electroplating processes and an electroless plating process.

Substrate

[0010] FIG. 1 includes a flow chart providing a process of forming an abrasive article in accordance with an embodiment. The process can be initiated at step 101 by bonding abrasive particles to a substrate by forming a first bonding region comprising metal on the substrate via electroplating

[0011] The substrate can provide a surface for affixing abrasive materials thereto, thus facilitating the abrasive capabilities of the abrasive article. For instance, the substrate can be in the form of a sheet, a wire, a wheel core, a platen, or a combination thereof. In a particular embodiment, the substrate can include a wheel core.

[0012] The substrate can be made of various materials, including for example, inorganic materials, organic materials (e.g., polymers and naturally occurring organic materials), and a combination thereof. Suitable inorganic materials can include ceramics, glasses, metals, metal alloys, cements, and a combination thereof. In certain instances, the substrate can be made of a metal or metal alloy material. For example, the substrate may be made of a transition metal or

transition metal alloy material and may incorporate elements of iron, nickel, cobalt, copper, chromium, molybdenum, vanadium, tantalum, tungsten, and a combination thereof. In a particular embodiment, the substrate can comprise steel. In a certain instance, the substrate can be formed of a majority of steel. In another instance, the substrate can consist essentially of steel.

[0013] Suitable organic materials can include polymers, which can include thermoplastics, thermosets, elastomers, and a combination thereof. Particularly useful polymers can include polyimides, polyamides, resins, polyurethanes, polyesters, and the like. It will further be appreciated that the substrate can include natural organic materials, for example, rubber.

First Bonding Region

[0014] In an embodiment, the first bonding region can be made of a material suitable for tacking and binding of abrasive particles for further processing. In accordance with an embodiment, the first bonding region can be formed from a metal, metal alloy, metal matrix composite, and a combination thereof. In one particular embodiment, the first bonding region can be formed of a material including a transition metal element. For example, the first bonding region can be a metal alloy including a transition metal element. Some suitable transition metal elements can include, lead, silver, copper, zinc, indium, tin, titanium, molybdenum, chromium, iron, manganese, cobalt, niobium, tantalum, tungsten, palladium, platinum, gold, ruthenium, and a combination thereof.

[0015] According to one particular embodiment, the first bonding region can include nickel. In another embodiment, the first bonding region can be made of a material having a majority content of nickel. For example, the first bonding region can be made of a material having at least 50 wt% nickel, such as at least 55 wt% nickel, at least 60 wt% nickel, at least 65 wt% nickel, at least 70 wt% nickel, at least 75 wt% nickel, at least 80 wt% nickel, at least 85 wt% nickel, at least 90 wt% nickel, at least 95 wt% nickel, at least 98wt% nickel, or even at least 99 wt% wt% nickel. In other non-limiting embodiments, the first bonding region can be made of a material having not greater than 100 wt% nickel, such as not greater than 99 wt% nickel, not greater than 98 wt% nickel, not greater than 95 wt% nickel, not greater than 90 wt% nickel, not greater than 85 wt% nickel, or even not greater than 80 wt% nickel. It will be appreciated that the first

bonding region can be made of a material having nickel within any minimum or maximum range noted above. In certain embodiments, the first bonding region may consist essentially of nickel.

[0016] The process of forming a first bonding region can include a deposition process, including for example, spraying, printing, dipping, die coating, plating (electroplating or electroless plating), and a combination thereof. The first bonding region can be bonded directly to a top surface of the substrate. In fact, the first bonding region can be formed such that it overlies a majority of the top surface of the substrate. In a particular embodiment, the first bonding region can be formed via electroplating, or by an electroplating or electrolyte plating process. In a particular embodiment, the first bonding region can include electroplated nickel.

[0017] In an embodiment, the first bonding region can include a layer. In a certain aspect, the first bonding region can be a substantially uniform layer.

[0018] According to one aspect, the first bonding region can be overlying a surface of a substrate, such that it may be in direct contact with the surface of the substrate, and more particularly, can be bonded directly to the surface of the substrate. In one aspect, the first bonding region can be formed such that it can directly contact at least a portion of abrasive particles or at least a portion of a region of abrasive particle, at least a portion of secondary particles, a second bonding region, a third bonding region, and a combination thereof. In one particular embodiment, the first bonding region can be disposed between the substrate and other overlying regions or regions, including for example, a region of abrasive particle, a region of a secondary particles, a second bonding region, a third bonding region, and a combination thereof.

Abrasive Particles

[0019] Reference herein to abrasive particles is reference to any one of the multiple types of abrasive particle described herein. The types of abrasive particles are described in more detail herein. In accordance with an embodiment, the abrasive particles can be in the first bonding region, and in more particular embodiments the abrasive particles can be in direct contact with the first bonding region. More particularly, the abrasive particles can be in direct contact with an additional layer or region, such as a second bonding region overlying the first bonding region, as discussed further herein.

[0020] According to at least one embodiment, the abrasive particles can be based on at least one particle characteristic of the group consisting of hardness, friability, toughness, particle shape, crystalline structure, average particle size, composition, particle coating, grit size distribution, and a combination thereof. Moreover, it will be appreciated that reference herein to abrasive particles can include agglomerated particles including a binder phase, unagglomerated particles, and a combination thereof, including for instance, a first type that is an agglomerated particle and a second type that is an unagglomerated particle.

[0021] In accordance with an embodiment, the abrasive particles can be formed on or at least partially in or within the first bonding region. In a particular embodiment, a percentage of abrasive particles that are in or within the first bonding region can include a majority of the abrasive particles. In certain instances, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, or even at least 95% of the abrasive particles are formed on or at least partially in or within the first bonding region. In accordance with an embodiment, the first bonding region can be formed to be free of or exclude secondary abrasive particles.

[0022] The abrasive particles can include a material such as an oxide, a carbide, a nitride, a boride, an oxynitride, an oxyboride, diamond, and a combination thereof. In certain embodiments, the abrasive particles can incorporate a superabrasive material. For example, one suitable superabrasive material includes diamond. Another suitable superabrasive material includes cubic boron nitride. In some instances the abrasive particles can include diamond, cubic boron nitride, or a combination thereof. In particular instances, the abrasive particles can consist essentially of diamond.

[0023] In one embodiment, the abrasive particles can include a material having a Mohs hardness of at least 7. In other instances, the abrasive particles can have a Mohs hardness of at least 8, or even at least 9.

[0024] The abrasive particles can have a certain average particle size (D50). In accordance with an embodiment, the abrasive particles can have an average particle size (D50) of at least 320 microns, such as at least 350 microns, at least 400 microns, at least 450 microns, at least 500 microns, at least 550 microns, or at least 600 microns. In a non-limiting embodiment, the abrasive particles can have an average particle size (D50) of not greater than 2000 microns, such

as not greater than 1800 microns, not greater than 1500 microns, not greater than 1200 microns, not greater than 1000 microns, not greater than 900 microns, or not greater than 800 microns. It will be appreciated that the abrasive particles can have an average particle size (D50) within any minimum of maximum value noted above.

Second Bonding Region

[0025] After forming the first bonding region at step 101, the process can continue at step 102 by bonding secondary particles to the substrate by forming a second bonding region comprising metal overlying the first bonding region via electroplating in accordance with a particular embodiment.

[0026] In an embodiment, the second bonding region can include a layer. In a certain aspect, the second bonding region can be a substantially uniform layer. In another aspect, the second bonding region can be overlying and in direct contact with the first bonding region. In another aspect, the second bonding region can be spaced apart from the substrate by the first bonding region.

[0027] According to one embodiment, the second bonding region can include a same material as the first bonding region, such that the compositions of the second bonding region and the first bonding region share at least one element in common. In yet an alternative embodiment, the second bonding region and the first bonding region can be entirely different materials. In a particular embodiment, however, the second bonding region can consist essentially of the same material as the first bonding region.

[0028] For instance, the second bonding region can be made of a material suitable for tacking and binding of abrasive particles for further processing. In accordance with an embodiment, the second bonding region can be formed from a metal, metal alloy, metal matrix composite, and a combination thereof. In one particular embodiment, the second bonding region can be formed of a material including a transition metal element. For example, the second bonding region can be a metal alloy including a transition metal element. Some suitable transition metal elements can include, lead, silver, copper, zinc, indium, tin, titanium, molybdenum, chromium, iron,

manganese, cobalt, niobium, tantalum, tungsten, palladium, platinum, gold, ruthenium, and a combination thereof.

[0029] According to one particular embodiment, the second bonding region can include nickel. In another embodiment, the second bonding region can be made of a material having a majority content of nickel. For example, the second bonding region can be made of a material having at least 50 wt% nickel, such as at least 55 wt% nickel, at least 60 wt% nickel, at least 65 wt% nickel, at least 70 wt% nickel, at least 75 wt% nickel, at least 80 wt% nickel, at least 85 wt% nickel, at least 90 wt% nickel, at least 95 wt% nickel, at least 98wt% nickel, or even at least 99 wt% wt% nickel. In other non-limiting embodiments, the second bonding region can be made of a material having not greater than 100 wt% nickel, such as not greater than 99 wt% nickel, not greater than 98 wt% nickel, not greater than 95 wt% nickel, not greater than 90 wt% nickel, not greater than 85 wt% nickel, or even not greater than 80 wt% nickel. It will be appreciated that the second bonding region can be made of a material having nickel within any minimum or maximum range noted above. In certain embodiments, the second bonding region may consist essentially of nickel.

[0030] The process of forming a second bonding region can include a deposition process, including for example, spraying, printing, dipping, die coating, plating (electroplating or electroless plating), and a combination thereof. The second bonding region can be bonded directly to the first bonding region. In a certain instance, the second bonding region can be bonded directly to a top surface of the first bonding region. In fact, the second bonding region can be formed such that it overlies a majority of the top surface of the first bonding region. In a particular embodiment, the second bonding region can be formed via electroplating, or by an electrolytic or electroplating process. In a particular embodiment, the second bonding region can include electroplated nickel.

Secondary Particles

[0031] In one particular embodiment, the second bonding region can include secondary particles, such that the secondary particles are disposed in, or within, at least a portion of the second bonding region. In an embodiment, the secondary particles can be contained at least partially within the second bonding region, such that not secondary particles are contained within the first

bonding region. In another particular embodiment, the secondary particles can be contained entirely within the second bonding region, such that no secondary particles are contained within the first bonding region.

[0032] Suitable methods of forming the second bonding region to include secondary particles can include various deposition methods, including but not limited to, spraying, gravity coating, dipping, die coating, dip coating, electrostatic coating, plating, and a combination thereof. According to one particular embodiment, the process of forming the second bonding region can include simultaneous application of the secondary particles. In a certain embodiment, the process of forming the second bonding region can include simultaneously forming the second bonding region to include secondary particles via an electroplating process.

[0033] In accordance with an embodiment, the second bonding region can be in direct contact with the first bonding region and an interface between the first bonding region and the second bonding region can be defined by lowermost points of a majority of secondary abrasive particles nearest the substrate.

[0034] In accordance with an embodiment, the secondary particles can be the same as the abrasive particles. In another embodiment, the secondary abrasive particles can be different than the abrasive particles. The secondary particles can include a material such as an oxide, a carbide, a nitride, a boride, an oxynitride, an oxyboride, diamond, and a combination thereof. In certain embodiments, the secondary particles can incorporate a superabrasive material. For example, one suitable superabrasive material includes diamond. Another suitable superabrasive material includes cubic boron nitride. In some instances the secondary particles can include diamond, cubic boron nitride, or a combination thereof. In particular instances, the secondary particles can consist essentially of diamond.

[0035] In one embodiment, the secondary particles can include a material having a Mohs hardness of at least 7. In other instances, the secondary abrasive particles can have a Mohs hardness of at least 8, or even at least 9.

[0036] In accordance with an embodiment, the secondary particles can have an average particle size (D50) that is less than the average particle size (D50) of the abrasive particles. In certain

instances, the secondary particles can have a certain average particle size (D50) of at least 1 micron, such as at least 5 microns, at least 10 microns, at least 50 microns, at least 80 microns, at least 100 microns, at least 120 microns, or at least 150 microns. In a non-limiting embodiment, the secondary particles can have an average particle size (D50) of not greater than 350 microns, such as not greater than 320 microns, not greater than 300 microns, not greater than 250 microns, not greater than 200 microns, not greater than 180 microns, not greater than 160 microns, not greater than 140 microns, not greater than 120 microns, or not greater than 100 microns. It will be appreciated that the secondary particles can have an average particle size (D50) within any minimum of maximum value noted above.

[0037] In accordance with an embodiment, the average particle size (D50) of the abrasive particles and the secondary particles can be compared with respect to each other. For instance, the abrasive article can include a ratio of secondary particles to abrasive particles, (SP(D50)/AP(D50)), of not greater than 1, wherein SP(D50) represents the average particle size of the secondary particles and AP(D50) represents the average particle size of the abrasive particles. In an embodiment, the ratio (SP(D50)/AP(D50)) can be not greater than 0.9, such as not greater than 0.8, not greater than 0.7, not greater than 0.6, not greater than 0.5, not greater than 0.4, not greater than 0.3, not greater than 0.25, or even not greater than 0.2. In a non-limiting embodiment, the ratio (SP(D50)/AP(D50)) is at least 0.01, such as at least 0.05, at least 0.08, at least 0.09, at least 0.1, at least 0.12, at least 0.15, or even at least 0.2. It will be appreciated that the ratio (SP(D50)/AP(D50)) can be within any minimum or maximum value noted above.

Third Bonding Region

[0038] After forming the second bonding region at step 102, the process can continue at step 103 by forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating, in accordance with a particular embodiment.

[0039] In an embodiment, the third bonding region can include a layer. In a certain aspect, the third bonding region can be a substantially uniform layer. In another aspect, the third bonding region can be overlying and in direct contact with the second bonding region. In another aspect,

the third bonding region can be spaced apart from the substrate by the first bonding region and the second bonding region.

[0040] According to one embodiment, the third bonding region can include a same material as the first bonding region and/or the second bonding region, such that the compositions of the third bonding region and the first and/or second bonding region(s) share at least one element in common. In yet an alternative embodiment, the third bonding region and the first and/or second bonding region(s) can be formed of entirely different materials. In a particular embodiment, however, the third bonding region can consist essentially of the same material as the first and/or second bonding region(s).

[0041] In accordance with an embodiment, the third bonding region can be formed from a metal, metal alloy, metal matrix composite, and a combination thereof. In one particular embodiment, the third bonding region can be formed of a material including a transition metal element. For example, the third bonding region can be a metal alloy including a transition metal element. Some suitable transition metal elements can include, lead, silver, copper, zinc, indium, tin, titanium, molybdenum, chromium, iron, manganese, cobalt, niobium, tantalum, tungsten, palladium, platinum, gold, ruthenium, and a combination thereof.

[0042] According to one particular embodiment, the third bonding region can include nickel. In another embodiment, the third bonding region can be made of a material having a majority content of nickel. For example, the third bonding region can be made of a material having at least 50 wt% nickel, such as at least 55 wt% nickel, at least 60 wt% nickel, at least 65 wt% nickel, at least 70 wt% nickel, at least 75 wt% nickel, at least 80 wt% nickel, at least 85 wt% nickel, at least 90 wt% nickel, at least 95 wt% nickel, at least 98wt% nickel, or even at least 99 wt% wt% nickel. In other non-limiting embodiments, the third bonding region can be made of a material having not greater than 100 wt% nickel, such as not greater than 99 wt% nickel, not greater than 98 wt% nickel, not greater than 95 wt% nickel, not greater than 90 wt% nickel, not greater than 85 wt% nickel, or even not greater than 80 wt% nickel. It will be appreciated that the third bonding region can be made of a material having nickel within any minimum or maximum range noted above. In certain embodiments, the third bonding region may consist essentially of nickel.

[0043] The process of forming a third bonding region can include a deposition process, including for example, spraying, printing, dipping, die coating, plating (electroplating or electroless plating), and a combination thereof. The third bonding region can be bonded directly to and overlying at least a portion of a surface of the second bonding region. In a certain instance, the second bonding region can be bonded directly to a top surface of the first bonding region. In fact, the second bonding region can be formed such that it overlies a majority of the top surface of the second bonding region. In another particular embodiment, the third bonding region can be formed such that it overlies and is in direct contact with a surface portion of the second bonding region not occupied by abrasive particles and secondary particles. In one aspect, the third bonding region can be formed such that it can directly contact at least a portion of the abrasive particles, secondary particles, the second bonding region, or a combination thereof.

[0044] In a particular embodiment, the second bonding region can be formed via electroless plating, or by an electroless plating process. In a particular embodiment, the second bonding region can include electroless plated nickel.

[0045] Electroless plating involves metal ions are reduced to metal through the action of chemical reducing agents serving as electron donors. The metal ions are electronic acceptors which react with the electron donors to form a metal which becomes deposited on the substrate. A catalyst may be present, which serves to accelerate the electroless chemical reaction to allow oxidation and reduction of the metal ion to metal. However, electroless plating does not need a current as used in conventional electroplating processes.

[0046] In one particular embodiment, the third bonding region can include secondary particles, such that the secondary particles are disposed in, or within, at least a portion of the third bonding region. In a non-limiting embodiment, both the second bonding region and the third bonding region can include secondary particles, such that the secondary particles are disposed in, or within, both the second bonding region and the third bonding region. In a particular embodiment, the secondary particles can be contained entirely within the second bonding region and the third bonding region, such that no secondary particles are contained within the first bonding region. In another particular embodiment, the secondary particles can be contained entirely within the second bonding region and the third bonding region, such that the secondary

particles are contained completely beneath a top surface of the third bonding layer, and are not exposed above the top surface of the third bonding layer. In an embodiment, the secondary particles disposed in the second bonding region and the third bonding region can be the same secondary particles. In another embodiment, the secondary particles disposed in the second bonding region and the third bonding region can be difference compared to each other.

An Article According to an Embodiment

[0047] FIG. 2 includes an illustration of a side plan view of a portion of an abrasive article 200 in accordance with an embodiment. As illustrated, abrasive article 200 includes abrasive particles 205 bonded to a substrate 201. FIG. 1 further illustrates a first bonding region 202 overlying the substrate 201, a second bonding region 203 overlying the first bonding region 202 and a third bonding region 204 overlying the second bonding region 203. The abrasive particles 205 can be disposed in and bonded to the first bonding region 202, the second bonding region 203 and the third bonding region 204. The abrasive article 200 can further include secondary particles 207. The secondary particles 207 can be disposed in and bonded to the second bonding region 203 and the third bonding region 204. Notably, as illustrated, the first bonding region 202 can be free of secondary particles 207.

[0048] In accordance with an embodiment, the first bonding region 202 can be formed to have an average thickness 221 (T1) of at least 5% of the average particle size of the abrasive particles 205, such as at least 8%, at least 10%, at least 12%, at least 15% , at least 18% , at least 20% , at least 22%, at least 25%, or at least 27% the average particle size of the abrasive particles 205. In a non-limiting embodiment, the first bonding region 202 can be formed to have an average thickness 221 (T1) of not greater than 50% of the average particle size of the abrasive particles, such as not greater than 45%, not greater than 40%, not greater than 35%, not greater than 30%, not greater than 27%, not greater than 25%, not greater than 22%, not greater than 20%, or not greater than 18% the average particle size of the abrasive particles 205. It will be appreciated that the first bonding region 202 can be formed to have an average thickness 221 (T1) with respect the average particle size of the abrasive particles 205 within a range of any minimum or maximum value noted above.

[0049] In accordance with an embodiment, the second bonding region 203 can be formed to have an average thickness 222 (T2) of at least 5% of the average particle size of the abrasive particles 205of at least 10% of, such as at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, or even at least 60%. In a non-limiting embodiment, the second bonding region 203 can be formed to have an average thickness 222 (T2) of not greater than 90% of the average particle size of the abrasive particles 205, such as not greater than 85%, not greater than 80%, not greater than 75%, not greater than 70%, not greater than 65%, not greater than 60%, not greater than 55%, not greater than 50%, or not greater than 45% the average particle size of the abrasive particles 205. It will be appreciated that the second bonding region 203 can be formed to have an average thickness 222 (T2) with respect the average particle size of the abrasive particles 205 within a range of any minimum or maximum value noted above.

[0050] In accordance with an embodiment, the second bonding region 203 can be formed to have an average thickness 222 (T2) that is substantially equal average thickness of the first bonding region 221.

[0051] In accordance with an embodiment, the first bonding region 202 and second bonding region 203 can have a total average thickness that is not greater than 100% of the average particle size of the abrasive particles 205, such as not greater than 90%, not greater than 85%, not greater than 80%, not greater than 75%, not greater than 70%, not greater than 65%, not greater than 60%, not greater than 55%, not greater than 50%, not greater than 45%, not greater than 40%, not greater than 35%, or not greater than 30% of the average particle size of the abrasive particles 205. In a non-limiting embodiment, the first bonding region 202 and the second bonding region 203 can have a total average thickness that is at least 20% of the average particle size of the abrasive particles 205, such as at least 40%, at least 45%, at least 50%, at least 60%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%. It will be appreciated that the first bonding region 202 and second bonding region 203 can be formed to have a total average thickness with respect the average particle size of the abrasive particles 205 within a range of any minimum or maximum value noted above. In a particular embodiment, the first bonding region 202 and second bonding region 203 can be formed to have a total average thickness within a

range of 20%-60%, and more particularly within a range of 30%-50% of the average size of the abrasive particles 205.

[0052] In accordance with an embodiment, the third bonding region 204 can be formed to have an average thickness 223 (T3) of at least 5% of the average particle size of the abrasive particles 205of at least 10% of, such as at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, or even at least 60%. In a non-limiting embodiment, the third bonding region 204 can be formed to have an average thickness 223 (T3) of not greater than 90% of the average particle size of the abrasive particles 205, such as not greater than 85%, not greater than 80%, not greater than 75%, not greater than 70%, not greater than 65%, not greater than 60%, not greater than 55%, not greater than 50%, or not greater than 45% the average particle size of the abrasive particles 205. It will be appreciated that the third bonding region 204 can be formed to have an average thickness 223 (T3) with respect the average particle size of the abrasive particles 205 within a range of any minimum or maximum value noted above.

[0053] In accordance with an embodiment, the third bonding region 204 can be formed to have an average thickness 223 (T3) that is substantially equal average thickness of the first bonding region 221 (T2) and or the second bonding region 223 (T2).

[0054] In accordance with an embodiment, the first bonding region 202, second bonding region 203 and third bonding region 204 can have a total average thickness 224 that is not greater than 100% of the average particle size of the abrasive particles 205, such as not greater than 90%, not greater than 85%, not greater than 80%, not greater than 75%, not greater than 70%, not greater than 65%, not greater than 60%, not greater than 55%, not greater than 50%, not greater than 45%, not greater than 40%, not greater than 35%, or not greater than 30% of the average particle size of the abrasive particles 205. In a non-limiting embodiment, the first bonding region 202, second bonding region 203 and third bonding region 204 can have a total average thickness 224 that is at least 20% of the average particle size of the abrasive particles 205, such as at least 40%, at least 45%, at least 50%, at least 60%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%. It will be appreciated that the first bonding region 202, second bonding region 203 and third bonding region 204 can have a total average thickness 224 can be formed to have a

total average thickness with respect the average particle size of the abrasive particles 205 within a range of any minimum or maximum value noted above. In a particular embodiment, the first bonding region 202, second bonding region 203 and third bonding region 204 can have a total average thickness 224 can be formed to have a total average thickness within a range of 50%-80%, and more particularly within a range of 60%-70% of the average size of the abrasive particles 205.

[0055] In an embodiment, the abrasive particles 205 can be exposed above a surface of the third bonding region204. In an embodiment, the abrasive particles 205 can be exposed above a surface of the third bonding region 204 by at least 5% of the average particle size (D50) of the abrasive particles 205, at least 10%, at least 15%, at least 20%. In an embodiment, the abrasive particles 205 can be exposed above a surface of the third bonding region 204 by not greater than 50% of the average particle size (D50) of the abrasive particles 205, not greater than 45%, not greater than 40%, not greater than 35%, not greater than 30%, not greater than 25%, not greater than 20%. It will be appreciated that increasing exposure of abrasive grains 205 above a top surface of the third bonding layer 204 can facilitate an increase in performance of the abrasive article 200.

[0056] Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein. After reading this specification, skilled artisans will appreciate that those aspects and embodiments are only illustrative and do not limit the scope of the present invention. Embodiments may be in accordance with any one or more of the items as listed below.

Embodiments

[0057] Embodiment 1. An abrasive article comprising:

a substrate;

a first bonding region comprising metal overlying the substrate;

a second bonding region comprising metal overlying the first bonding region;

abrasive particles contained in the first bonding region and the second bonding region, the abrasive particles having an average particle size (D50) of at least 320 microns; and

a third bonding region comprising metal overlying at least a portion of the abrasive particles and overlying the second bonding region.

[0058] Embodiment 2. The abrasive article of embodiment 1, wherein the first bonding region is a region, wherein the first bonding region is a substantially uniform region, wherein the first bonding region is in direct contact with the substrate.

[0059] Embodiment 3. The abrasive article of embodiment 1, wherein the second bonding region is a region, wherein the second bonding region is a substantially uniform region, wherein the second bonding region is overlying and in direct contact with the first bonding region, wherein the second bonding region is spaced apart from the substrate by the first bonding region.

[0060] Embodiment 4. The abrasive article of embodiment 1, wherein the third bonding region is a region, wherein the third bonding region is a substantially uniform region, wherein the third bonding region is overlying and in direct contact with the second bonding region, wherein the third bonding region is spaced apart from the substrate by the first bonding region and the second bonding region.

[0061] Embodiment 5. The abrasive article of embodiment 1, wherein the first bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the first binding region comprises nickel, wherein the first bonding region comprises electroplated nickel, wherein the first bonding region consists essentially of electroplated nickel.

[0062] Embodiment 6. The abrasive article of embodiment 1, wherein the second bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the second binding region comprises nickel, wherein the second bonding region comprises electroplated nickel, wherein the second bonding region consists essentially of electroplated nickel.

[0063] Embodiment 7. The abrasive article of embodiment 1, wherein the third bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the third binding region comprises nickel, wherein the third bonding region comprises electroless plated nickel, wherein the third bonding region consists essentially of electroless plated nickel.

[0064] Embodiment 8. The abrasive article of embodiment 1, wherein the abrasive particles comprise an average particle size (D50) of at least 350 microns or at least 400 microns or at least 450 microns or at least 500 microns or at least 550 microns or at least 600 microns.

[0065] Embodiment 9. The abrasive article of embodiment 1, wherein the abrasive particles comprise an average particle size (D50) of not greater than 2000 microns or not greater than 1800 microns or not greater than 1500 microns or not greater than 1200 microns or not greater than 1000 microns or not greater than 900 microns or not greater than 800 microns.

[0066] Embodiment 10. The abrasive article of embodiment 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the average particle size (D50) of the abrasive particles, at least 25% the average particle size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.

[0067] Embodiment 11. The abrasive article of embodiment 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.

[0068] Embodiment 12. The abrasive article of embodiment 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.

[0069] Embodiment 13. The abrasive article of embodiment 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the average particle size (D50) of the abrasive particles, at least 25% the average particle

size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.

[0070] Embodiment 14. The abrasive article of embodiment 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.

[0071] Embodiment 15. The abrasive article of embodiment 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.

[0072] Embodiment 16. The abrasive article of embodiment 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the average particle size (D50) of the abrasive particles, at least 25% the average particle size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.

[0073] Embodiment 17. The abrasive article of embodiment 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.

[0074] Embodiment 18. The abrasive article of embodiment 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.

[0075] Embodiment 19. The abrasive article of embodiment 1, further comprising secondary particles disposed in the second bonding region, wherein the third bonding region comprises secondary particles, wherein the secondary particles in the second bonding region and third bonding region are the same secondary particles, wherein the secondary particles in the second bonding region and the third bonding region are different compared to each other.

[0076] Embodiment 20. The abrasive article of embodiment 1, wherein the substrate comprises a wheel core.

[0077] Embodiment 21. The abrasive article of embodiment 1, wherein the substrate comprises metal.

[0078] Embodiment 22. The abrasive article of embodiment 1, wherein the abrasive particles have a Mohs hardness of at least 7 or at least 8 or at least 9, wherein the abrasive particles comprise a superabrasive material, wherein the abrasive particles comprise diamond, cubic boron nitride or a combination thereof., wherein the abrasive particles consist essentially of diamond.

[0079] Embodiment 23. The abrasive article of embodiment 22, wherein the secondary particles are contained entirely within the second bonding region and the third bonding region.

[0080] Embodiment 24. The abrasive article of embodiment 22, wherein the secondary particles have an average particles size (D50) that is less than the average particle size (D50) of the abrasive particles.

[0081] Embodiment 25. The abrasive article of embodiment 22, wherein the secondary particles have an average particle size (D50) of at least 1 micron or at least 5 microns or at least 10 microns or at least 50 microns or at least 80 microns or at least 100 microns or at least 120 microns or at least 150 microns.

[0082] Embodiment 26. The abrasive article of embodiment 22, wherein the secondary particles comprise an average particle size (D50) of not greater than 300 microns or not greater than 350 microns or not greater than 250 microns or not greater than 200 microns or not greater than 180 microns or not greater than 160 microns or not greater than 140 microns or not greater than 120 microns or not greater than 100 microns.

[0083] Embodiment 27. The abrasive article of embodiment 22, wherein the secondary particles include an inorganic material selected from the group consisting of oxides, borides, nitrides, oxyborides, oxycarbides, oxynitrides, carbon, diamond, or any combination thereof, wherein the secondary particles have a Mohs hardness of at least 7 or at least 8 or at least 9, wherein the abrasive particles comprise a superabrasive material, wherein the abrasive particles comprise diamond, cubic boron nitride or a combination thereof., wherein the abrasive particles consist essentially of diamond.

[0084] Embodiment 28. The abrasive article of embodiment 22, further comprising a ratio (SP(D50)/AP(D50)) of not greater than 1, wherein SP(D50) represents the average particle size of the secondary particles and AP(D50) represents the average particle size of the abrasive particles, wherein the ratio (SP(D50)/AP(D50)) is not greater than 0.9 or not greater than 0.8 or not greater than 0.7 or not greater than 0.6 or not greater than 0.5 or not greater than 0.4 or not greater than 0.3 or not greater than 0.25 or not greater than 0.2.

[0085] Embodiment 29. The abrasive article of embodiment 22, further comprising a ratio (SP(D50)/AP(D50)) of not greater than 0.01, wherein SP(D50) represents the average particle size of the secondary particles and AP(D50) represents the average particle size of the abrasive particles, wherein the ratio (SP(D50)/AP(D50)) is at least 0.05 or at least 0.08 or at least 0.09 or at least 0.1 or at least 0.12 or at least 0.15 or at least 0.2.

[0086] Embodiment 30. The abrasive article of embodiment 22, wherein the first bonding region excludes or is free of secondary particles.

[0087] Embodiment 31. An abrasive article comprising:

a substrate;

a first bonding region comprising metal overlying the substrate;

abrasive particles disposed in the first bonding region;

a second bonding region comprising metal overlying the first bonding region;

secondary particles disposed in the second bonding region;

a third bonding region comprising metal overlying the second bonding region;

wherein the third bonding region comprises an electroless plated region.

[0088] Embodiment 32. The abrasive article of embodiment 31, wherein the first bonding region excludes or is free of secondary particles.

[0089] Embodiment 33. The abrasive article of embodiment 31, wherein the first bonding region and the second bonding region are electroplated regions.

[0090] Embodiment 34. The abrasive article of embodiment 31, wherein the second bonding region is in direct contact with the first bonding region and wherein an interface between the first bonding region and the second bonding region is defined by lowermost points of a majority of secondary abrasive particles nearest the substrate.

[0091] Embodiment 35. The abrasive article of embodiment 31, wherein the abrasive particles are exposed above a surface of the third bonding region.

[0092] Embodiment 36. The abrasive article of embodiment 35, wherein the abrasive particles are exposed above a surface of the third bonding region by at least 5% of the average particle size (D50) of the abrasive particles, at least 10%, at least 15%, at least 20%.

[0093] Embodiment 37. The abrasive article of embodiment 35, wherein the abrasive particles are exposed above a surface of the third bonding region by not greater than 50% of the average particle size (D50) of the abrasive particles, not greater than 45%, not greater than 40%, not greater than 35%, not greater than 30%, not greater than 25%, not greater than 20%.

[0094] Embodiment 38. A method of making an abrasive article comprising:

bonding abrasive particles to a substrate by forming a first bonding region comprising metal on the substrate via electroplating;

bonding secondary particles abrasive particles to the substrate by forming a second bonding region comprising metal overlying the first bonding region via electroplating;

forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating.

[0095] Embodiment 39. The method of embodiment 38, wherein the first bonding region is free of secondary particles.

[0096] Embodiment 40. The method of embodiment 38, wherein the first bonding region is formed to have an average thickness (T1) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.

[0097] Embodiment 41. The method of embodiment 38, wherein the first bonding region is formed to have an average thickness (T1) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

[0098] Embodiment 42. The method of embodiment 38, wherein the second bonding region is formed to have an average thickness (T2) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.

[0099] Embodiment 43. The method of embodiment 38, wherein the second bonding region is formed to have an average thickness (T2) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

[00100] Embodiment 44. The method of embodiment 38, wherein the second bonding region is formed to have an average thickness (T2) substantially equal to an average thickness of the first bonding region (T1).

[00101] Embodiment 45. The method of embodiment 38, wherein the third bonding region is formed to have an average thickness (T3) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.

[00102] Embodiment 46. The method of embodiment 38, wherein the third bonding region is formed to have an average thickness (T3) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or

not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

[00103] Embodiment 47. The method of embodiment 38, wherein the third bonding region is formed to have an average thickness (T3) substantially equal to an average thickness of the first bonding region (T1).

[00104] Embodiment 48. The method of embodiment 38, wherein the third bonding region is formed to have an average thickness (T3) substantially equal to an average thickness of the second bonding region (T2).

[00105] Embodiment 49. The method of embodiment 38, wherein the first bonding region, the second bonding region, and the third bonding region have a total average thickness that is not greater than 100% of the average particle size of the abrasive particles or not greater than 90% or not greater than 85% or not greater than 80% or not greater than 75% or not greater than 70% or not greater than 65%.

[00106] Embodiment 50. The method of embodiment 38, wherein the first bonding region, the second bonding region, and the third bonding region have a total average thickness that is at least 40% of the average particle size of the abrasive particles or at least 50% or at least 60% or at least 70% or at least 75% or at least 80% or at least 85% or at least 90%.

[00107] Embodiment 51. The method of embodiment 38, wherein the secondary particles are bonded simultaneously during formation of the second bonding region.

EXAMPLE 1:

[00108] Comparative sample CS1 will be formed according to the following procedure. An electroplated bonding region of nickel will be formed directly on a substrate of steel. Abrasive particles will be bonded to the substrate by the electroplated bonding region. The abrasive particles will have an average particle size of approximately 300 microns. After forming electroplated bonding region, an electroless plated region of nickel will be formed overlying the electroplated bonding region and abrasive particles.

EXAMPLE 2:

[00109] Sample SN1 will be formed according to the following procedure. An electroplated bonding region of nickel directly on a steel substrate. Abrasive particles will be bonded to the substrate by the electroplated bonding region. The abrasive particles will have an average particle size of approximately 600 microns. After forming the electroplated bonding region, an electroless plated region of nickel will be formed overlying the electroplated bonding region and abrasive particles.

EXAMPLE 3:

[00110] Sample SN2 will be formed according to the following procedure. An electroplated bonding region of nickel directly on a steel substrate. Abrasive particles will be bonded to the substrate by the electroplated bonding region. The abrasive particles will have an average particle size of approximately 800 microns. After forming the electroplated bonding region, an electroless plated region of nickel will be formed overlying the electroplated bonding region and abrasive particles.

EXAMPLE 4:

[00111] Sample SN3 will be formed according to the following procedure. An electroplated bonding region of nickel directly on a steel substrate. Abrasive particles will be bonded to the substrate by the electroplated bonding region. The abrasive particles will have an average particle size of approximately 1000 microns. After forming the electroplated bonding region, an electroless plated region of nickel will be formed overlying the electroplated bonding region and abrasive particles.

[00112] The samples of SN1, SN2 and SN3 are expected to facilitate higher performance in comparison to sample CS1.

EXAMPLE 5:

[00113] Comparative sample CS2 is made by bonding abrasive particles to a substrate by forming electroplated bonding regions according to Table 1 below. Sample CS2 does not include an electroless plated layer or secondary particles.

[00114] Sample SN4 is made in accordance to embodiments herein and as detailed in Table 1 below, by bonding abrasive particles to a substrate by forming a first bonding region comprising metal on a substrate via electroplating, forming a second bonding region comprising metal overlying the first bonding region via electroplating, and forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating. Sample SN4 does not include secondary particles.

[00115] Sample SN5 is made in accordance to embodiments herein and as detailed in Table 1 below, by bonding abrasive particles to a substrate by forming a first bonding region comprising metal on a substrate via electroplating, bonding secondary particles to the substrate by forming a second bonding region comprising metal overlying the first bonding region via electroplating, and forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating.

TABLE 1:

	CS2	SN4	SN5
Number of electroplated regions	2	2	2
Avg. thickness of electroplated regions (based on avg. size of abrasive particles)	1st (20%) 2nd (55-70%)	1st (20%) 2nd (15-20%)	1st (20%) 2nd (4-20%)
Avg. size of abrasive particles	602 microns	602 microns	602 microns
Avg. size of secondary particles, if included.	none	none	20% of the avg. size of abrasive particles.
Avg. thickness of electroless plated region (based on avg. size of abrasive particles).	none	15-25%	15-25%
Avg. exposure of abrasive particles above top surface (based on avg. size of abrasive particles)	10-25%	30-35%	30-35%

[00116] Testing to evaluate deburring performance was performed on cast iron camshafts. Samples CS2, SN4 and SN5 took the form of a saw using diamond abrasive particles to deburr cast iron camshafts in automatic machine. Each saw was formed to have a diameters of about 406.4 mm, a thickness of about 4 mm, and a bore of about 31.75 mm.

[00117] The results of the deburring test are shown in FIG. 3. As illustrated, Comparative Sample CS2 had a baseline performance of 100%. Sample, SN4 had an improved performance over CS2 by about 75%, and Sample, SN5 had an improved performance over CS2 by about 144%.

[00118] The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The specification and illustrations are not intended to serve as an exhaustive and comprehensive description of all

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

[00119] The description in combination with the figures is provided to assist in understanding the teachings disclosed herein. The following discussion will focus on specific implementations and embodiments of the teachings. This focus is provided to assist in describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings. However, other teachings can certainly be used in this application.

[00120] As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or inherent to such method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[00121] Also, the use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the

invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise. For example, when a single item is described herein, more than one item may be used in place of a single item. Similarly, where more than one item is described herein, a single item may be substituted for that more than one item.

[00122] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and may be found in reference books and other sources within the structural arts and corresponding manufacturing arts.

[00123] The above-disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments, which fall within the true scope of the present invention. Thus, to the maximum extent allowed by law, the scope of the present invention is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

[00124] The Abstract of the Disclosure is provided to comply with Patent Law and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description of the Drawings, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description of the Drawings, with each claim standing on its own as defining separately claimed subject matter.

WHAT IS CLAIMED IS:

1. An abrasive article comprising:

    a substrate;

    a first bonding region comprising metal overlying the substrate;

    a second bonding region comprising metal overlying the first bonding region;

    abrasive particles contained in the first bonding region and the second bonding region, the abrasive particles having an average particle size (D50) of at least 320 microns; and

    a third bonding region comprising metal overlying at least a portion of the abrasive particles and overlying the second bonding region.

2. The abrasive article of claim 1, wherein the first bonding region is a region, wherein the first bonding region is a substantially uniform region, wherein the first bonding region is in direct contact with the substrate.

3. The abrasive article of claim 1, wherein the second bonding region is a region, wherein the second bonding region is a substantially uniform region, wherein the second bonding region is overlying and in direct contact with the first bonding region, wherein the second bonding region is spaced apart from the substrate by the first bonding region.

4. The abrasive article of claim 1, wherein the third bonding region is a region, wherein the third bonding region is a substantially uniform region, wherein the third bonding region is overlying and in direct contact with the second bonding region, wherein the third bonding region is spaced apart from the substrate by the first bonding region and the second bonding region.

5. The abrasive article of claim 1, wherein the first bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the first binding region comprises nickel, wherein the first bonding region comprises electroplated nickel, wherein the first bonding region consists essentially of electroplated nickel.

6. The abrasive article of claim 1, wherein the second bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the second binding region comprises nickel, wherein the second bonding region comprises electroplated nickel, wherein the second bonding region consists essentially of electroplated nickel.

7. The abrasive article of claim 1, wherein the third bonding region comprises a metal or metal alloy including at least one transition metal element, wherein the third binding region comprises nickel, wherein the third bonding region comprises electroless plated nickel, wherein the third bonding region consists essentially of electroless plated nickel.
8. The abrasive article of claim 1, wherein the abrasive particles comprise an average particle size (D50) of at least 350 microns or at least 400 microns or at least 450 microns or at least 500 microns or at least 550 microns or at least 600 microns.
9. The abrasive article of claim 1, wherein the abrasive particles comprise an average particle size (D50) of not greater than 2000 microns or not greater than 1800 microns or not greater than 1500 microns or not greater than 1200 microns or not greater than 1000 microns or not greater than 900 microns or not greater than 800 microns.
10. The abrasive article of claim 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the average particle size (D50) of the abrasive particles, at least 25% the average particle size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.
11. The abrasive article of claim 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.
12. The abrasive article of claim 1, wherein the first bonding region comprises a thickness (T1), and wherein the thickness (T1) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.
13. The abrasive article of claim 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the

average particle size (D50) of the abrasive particles, at least 25% the average particle size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.

14. The abrasive article of claim 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.
15. The abrasive article of claim 1, wherein the second bonding region comprises a thickness (T2), and wherein the thickness (T2) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.
16. The abrasive article of claim 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) is at least 5% the average particle size (D50) of the abrasive particles, at least 10% the average particle size (D50) of the abrasive particles, at least 15% the average particle size (D50) of the abrasive particles, at least 20% the average particle size (D50) of the abrasive particles, at least 25% the average particle size (D50) of the abrasive particles, at least 30% the average particle size (D50) of the abrasive particles, at least 35% the average particle size (D50) of the abrasive particles.
17. The abrasive article of claim 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) and not greater than 40% the average particle size (D50) of the abrasive particles, not greater than 35% the average particle size (D50) of the abrasive particles, not greater than 30% the average particle size (D50) of the abrasive particles, not greater than 25% the average particle size (D50) of the abrasive particles, not greater than 20% the average particle size (D50) of the abrasive particles.
18. The abrasive article of claim 1, wherein the third bonding region comprises a thickness (T3), and wherein the thickness (T3) is at least 15% and not greater than 25% the average particle size (D50) of the abrasive particles.
19. The abrasive article of claim 1, further comprising secondary particles disposed in the second bonding region, wherein the third bonding region comprises secondary particles, wherein the secondary particles in the second bonding region and third bonding region

are the same secondary particles, wherein the secondary particles in the second bonding region and the third bonding region are different compared to each other.

20. The abrasive article of claim 1, wherein the substrate comprises a wheel core.
21. The abrasive article of claim 1, wherein the substrate comprises metal.
22. The abrasive article of claim 1, wherein the abrasive particles have a Mohs hardness of at least 7 or at least 8 or at least 9, wherein the abrasive particles comprise a superabrasive material, wherein the abrasive particles comprise diamond, cubic boron nitride or a combination thereof., wherein the abrasive particles consist essentially of diamond.
23. The abrasive article of claim 22, wherein the secondary particles are contained entirely within the second bonding region and the third bonding region.
24. The abrasive article of claim 22, wherein the secondary particles have an average particles size (D50) that is less than the average particle size (D50) of the abrasive particles.
25. The abrasive article of claim 22, wherein the secondary particles have an average particle size (D50) of at least 1 micron or at least 5 microns or at least 10 microns or at least 50 microns or at least 80 microns or at least 100 microns or at least 120 microns or at least 150 microns.
26. The abrasive article of claim 22, wherein the secondary particles comprise an average particle size (D50) of not greater than 300 microns or not greater than 350 microns or not greater than 250 microns or not greater than 200 microns or not greater than 180 microns or not greater than 160 microns or not greater than 140 microns or not greater than 120 microns or not greater than 100 microns.
27. The abrasive article of claim 22, wherein the secondary particles include an inorganic material selected from the group consisting of oxides, borides, nitrides, oxyborides, oxycarbides, oxynitrides, carbon, diamond, or any combination thereof, wherein the secondary particles have a Mohs hardness of at least 7 or at least 8 or at least 9, wherein the abrasive particles comprise a superabrasive material, wherein the abrasive particles comprise diamond, cubic boron nitride or a combination thereof., wherein the abrasive particles consist essentially of diamond.
28. The abrasive article of claim 22, further comprising a ratio (SP(D50)/AP(D50)) of not greater than 1, wherein SP(D50) represents the average particle size of the secondary particles and AP(D50) represents the average particle size of the abrasive particles,

wherein the ratio (SP(D50)/AP(D50)) is not greater than 0.9 or not greater than 0.8 or not greater than 0.7 or not greater than 0.6 or not greater than 0.5 or not greater than 0.4 or not greater than 0.3 or not greater than 0.25 or not greater than 0.2.

29. The abrasive article of claim 22, further comprising a ratio (SP(D50)/AP(D50)) of not greater than 0.01, wherein SP(D50) represents the average particle size of the secondary particles and AP(D50) represents the average particle size of the abrasive particles, wherein the ratio (SP(D50)/AP(D50)) is at least 0.05 or at least 0.08 or at least 0.09 or at least 0.1 or at least 0.12 or at least 0.15 or at least 0.2.

30. The abrasive article of claim 22, wherein the first bonding region excludes or is free of secondary particles.

31. An abrasive article comprising:

a substrate;

a first bonding region comprising metal overlying the substrate;

abrasive particles disposed in the first bonding region;

a second bonding region comprising metal overlying the first bonding region;

secondary particles disposed in the second bonding region;

a third bonding region comprising metal overlying the second bonding region;

wherein the third bonding region comprises an electroless plated region.

32. The abrasive article of claim 31, wherein the first bonding region excludes or is free of secondary particles.

33. The abrasive article of claim 31, wherein the first bonding region and the second bonding region are electroplated regions.

34. The abrasive article of claim 31, wherein the second bonding region is in direct contact with the first bonding region and wherein an interface between the first bonding region and the second bonding region is defined by lowermost points of a majority of secondary abrasive particles nearest the substrate.

35. The abrasive article of claim 31, wherein the abrasive particles are exposed above a surface of the third bonding region.

36. The abrasive article of claim 35, wherein the abrasive particles are exposed above a surface of the third bonding region by at least 5% of the average particle size (D50) of the abrasive particles, at least 10%, at least 15%, at least 20%.

37. The abrasive article of claim 35, wherein the abrasive particles are exposed above a surface of the third bonding region by not greater than 50% of the average particle size (D50) of the abrasive particles, not greater than 45%, not greater than 40%, not greater than 35%, not greater than 30%, not greater than 25%, not greater than 20%.

38. A method of making an abrasive article comprising:

bonding abrasive particles to a substrate by forming a first bonding region comprising metal on the substrate via electroplating;

bonding secondary particles abrasive particles to the substrate by forming a second bonding region comprising metal overlying the first bonding region via electroplating;

forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating.

39. The method of claim 38, wherein the first bonding region is free of secondary particles.

40. The method of claim 38, wherein the first bonding region is formed to have an average thickness (T1) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.

41. The method of claim 38, wherein the first bonding region is formed to have an average thickness (T1) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

42. The method of claim 38, wherein the second bonding region is formed to have an average thickness (T2) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.

43. The method of claim 38, wherein the second bonding region is formed to have an average thickness (T2) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

44. The method of claim 38, wherein the second bonding region is formed to have an average thickness (T2) substantially equal to an average thickness of the first bonding region (T1).
45. The method of claim 38, wherein the third bonding region is formed to have an average thickness (T3) of at least 5% of the average particle size of the abrasive particles or at least 8% or at least 10% or at least 12% or at least 15% or at least 18% or at least 20% or at least 22% or at least 25% or at least 27%.
46. The method of claim 38, wherein the third bonding region is formed to have an average thickness (T3) of not greater than 50% of the average particle size of the abrasive particles or not greater than 45% or not greater than 40% or not greater than 35% or not greater than 30% or not greater than 27% or not greater than 25% or not greater than 22% or not greater than 20% or not greater than 18%.

47. The method of claim 38, wherein the third bonding region is formed to have an average thickness (T3) substantially equal to an average thickness of the first bonding region (T1).
48. The method of claim 38, wherein the third bonding region is formed to have an average thickness (T3) substantially equal to an average thickness of the second bonding region (T2).
49. The method of claim 38, wherein the first bonding region, the second bonding region, and the third bonding region have a total average thickness that is not greater than 100% of the average particle size of the abrasive particles or not greater than 90% or not greater than 85% or not greater than 80% or not greater than 75% or not greater than 70% or not greater than 65%.
50. The method of claim 38, wherein the first bonding region, the second bonding region, and the third bonding region have a total average thickness that is at least 40% of the average particle size of the abrasive particles or at least 50% or at least 60% or at least 70% or at least 75% or at least 80% or at least 85% or at least 90%.
51. The method of claim 38, wherein the secondary particles are bonded simultaneously during formation of the second bonding region.

ABSTRACT OF THE DISCLOSURE

An abrasive article includes a first bonding region including metal overlying a substrate, abrasive particles in the first bonding region, secondary particles disposed in a second bonding region including metal overlying the first bonding region, and a third bonding region overlying the second bonding region. The first and second bonding regions can be formed by an electroplating process, and the third bonding region can be formed by an electroless plating process. Secondary particles can be disposed in only the second bonding region and the third bonding region, and the first bonding region can be free of secondary particles.

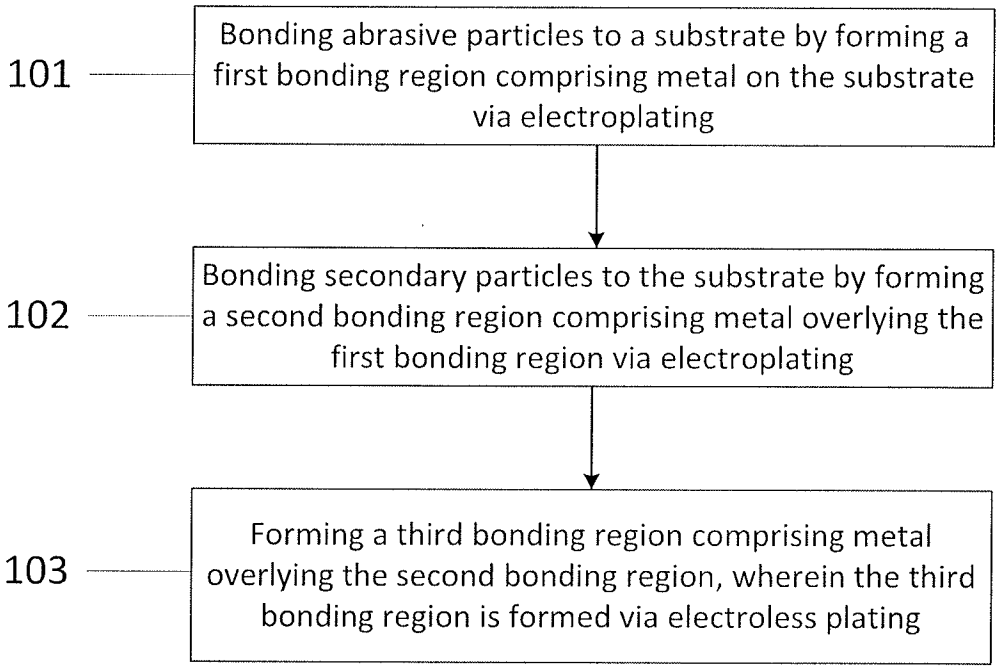
101
Bonding abrasive particles to a substrate by forming a first bonding region comprising metal on the substrate via electroplating
102
Bonding secondary particles to the substrate by forming a second bonding region comprising metal overlying the first bonding region via electroplating
103
Forming a third bonding region comprising metal overlying the second bonding region, wherein the third bonding region is formed via electroless plating

FIG. 1

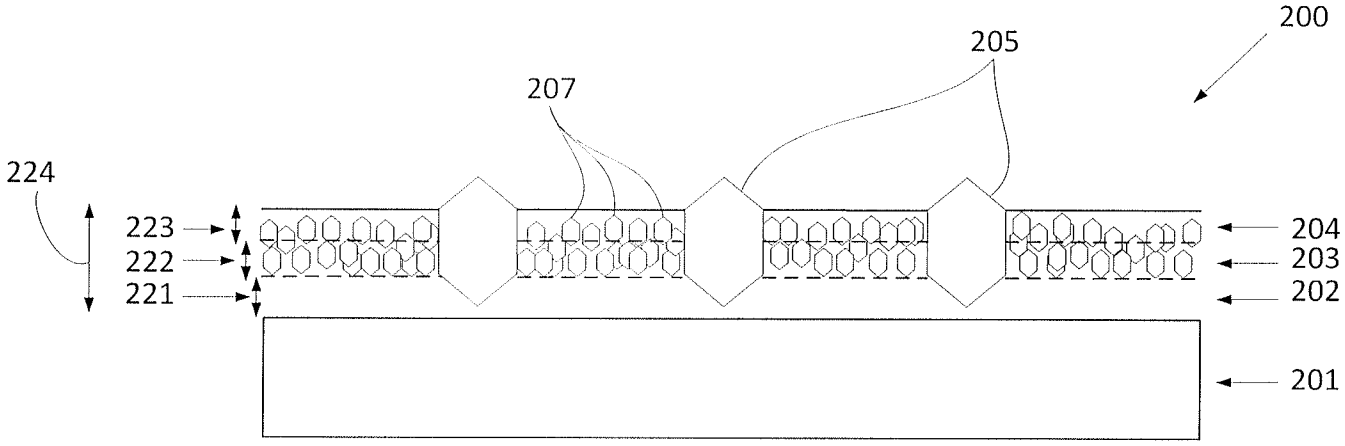

FIG. 2

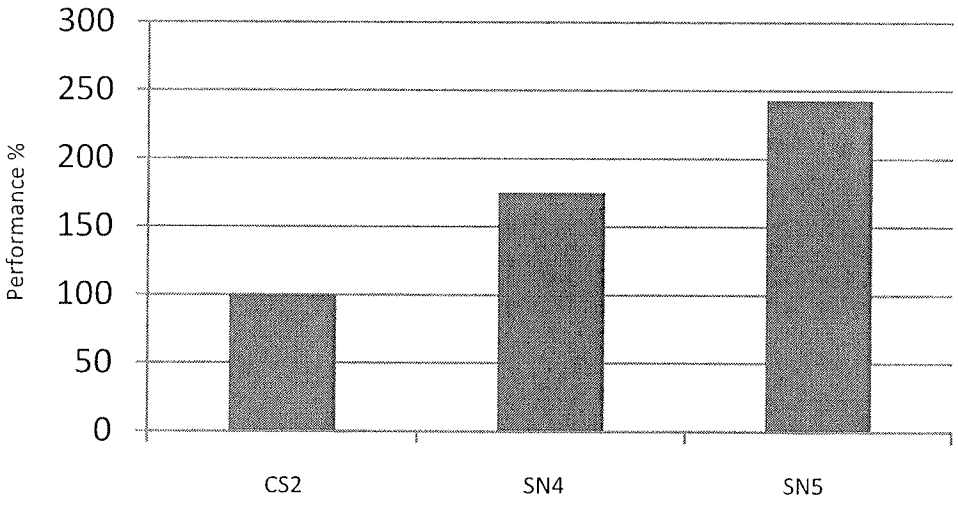

FIG. 3