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(54) Title: SUPERABRASIVE WHEEL WITH ACTIVE BOND

(57) Abstract

A straight, thin, monolithic abrasive wheel formed of hard and rigid abrasive grains and a sintered bond including a metal component and an active metal component exhibits superior stiffness. The metal component can be selected from among many sinterable metal compositions. The active metal is a metal capable of reacting to form a bond with the abrasive gains at sintering conditions and is present in an amount effective to integrate the grains and sintered bond into a grain–reinforced composite. A diamond abrasive, copper/tin/titanium sintered bond abrasive wheel is preferred. Such a wheel is useful for abrading operations in the electronics industry, such as cutting silicon wafers and alumina–titanium carbide pucks. The stiffness of the novel abrasive wheels is higher than conventional straight monolithic wheels and therefore improved cutting precision and less chipping can be attained without increase of wheel thickness and concomitant increased kerf loss.

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SUPERABRASIVE WHEEL WITH ACTIVE BOND

This invention relates to thin abrasive wheels for abrading very hard materials such as those utilized by the electronics industry.

Abrasive wheels which are both very thin and highly stiff are commercially important. For example, thin abrasive wheels are used in cutting off thin sections and in performing other abrading operations in the processing of silicon wafers and so-called pucks of alumina-titanium carbide composite in the manufacture of electronic products. Silicon wafers are generally used for integrated circuits and alumina-titanium carbide pucks are utilized to fabricate flying thin film heads for recording and playing back magnetically stored information. The use of thin abrasive wheels to abrade silicon wafers and alumina-titanium carbide pucks is explained well in U.S. Patent No. 5,313,742, the entire disclosure of which patent is incorporated herein by reference.

As stated in the '742 patent, the fabrication of silicon wafers and alumina-titanium carbide pucks creates the need for dimensionally accurate cuts with little waste of the work piece material. Ideally, cutting blades to effect such cuts should be as stiff as possible and as thin as practical because the thinner the blade, the less waste produced and the stiffer the blade, the more straight it will cut. However, these characteristics are in conflict because the thinner the blade, the less rigid it becomes.

Industry has evolved to using monolithic abrasive wheels, usually ganged together on an arbor-mounted axle. Individual wheels in the gang are axially separated from each other by incompressible and durable spacers. Traditionally, the individual wheels have a uniform axial dimension from the wheel's arbor hole to its periphery. Although quite thin, the axial dimension of these wheels is greater than desired to provide adequate stiffness for good accuracy of cut. However, to keep waste generation within acceptable bounds, the thickness is reduced. This diminishes rigidity of the wheel to less than the ideal.

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The conventional straight wheel is thus seen to generate more work piece waste than a thinner wheel and to produce more chips and inaccurate cuts than would a stiffer wheel. The '742 patent sought to improve upon performance of ganged straight wheels by increasing the thickness of an inner portion extending radially outward from the arbor hole. It was disclosed that a monolithic wheel with a thick inner portion was stiffer than a straight wheel with spacers. However, the '742 patent wheel suffers from the drawback that the inner portion is not used for cutting, and therefore, the volume of abrasive in the inner portion is wasted. Because thin abrasive wheels, especially those for cutting alumina-titanium carbide, employ expensive abrasive substances such as diamond, the cost of a '742 patent wheel is high compared to a straight wheel due to the wasted abrasive volume.

It is desirable to have a straight, monolithic, thin abrasive wheel having enhanced rigidity compared to conventional wheels. Aside from wheel geometry, rigidity is determined by the intrinsic stiffness of the materials of wheel construction. Monolithic wheels are made up basically of abrasive grains and a bond which holds the abrasive grains in the desired shape. Heretofore, a metal bond normally has been used for thin abrasive wheels intended for cutting hard materials such as silicon wafers and alumina-titanium carbide pucks. A variety of metal bond compositions for holding diamond grains, such as copper, zinc, silver, nickel, or iron alloys, for example, are known in the art. It now has been discovered that addition of at least one active metal component to a metal bond composition can cause the diamond grains to chemically react with the active metal component during bond formation thereby forming an integrated, grain-reinforced composite. The very high intrinsic stiffness of the grains together with the chemical bond of the grains to the metal thus produce a substantially increased stiffness abrasive structure.

Accordingly, the present invention provides an abrasive wheel comprising a straight, monolithic, grain-reinforced abrasive disk having a uniform width in the range of about 20 - 2,500 μm, consisting essentially of about 2.5- 50 vol.

% abrasive grains and a complemental amount of a bond comprising a metal component and an active metal which forms a chemical bond with the abrasive grains on sintering, the active metal being present in an amount effective to produce an elastic modulus of the grain-reinforced abrasive disk at least 10% higher than the elastic modulus of a sintered disk of same composition but free of active metal.

There is also provided a method of cutting a work piece comprising the step of contacting the work piece with an abrasive wheel comprising a straight, monolithic, grain-reinforced abrasive disk having a uniform width in the range of about 20 - 2,500 µm, consisting essentially of about 2.5- 50 vol. % abrasive grains and a complemental amount of a bond comprising a metal component and an active metal which forms a chemical bond with the abrasive grains on sintering, the active metal being present in an amount effective to produce an elastic modulus of the grain-reinforced abrasive disk at least 10% higher than the elastic modulus of a sintered disk of same composition but free of active metal.

Further this invention provides a method of making an abrasive tool comprising the steps of

- (a) providing preselected proportions of particulate ingredients comprising
  - (1) abrasive grains;
  - (2) a metal component consisting essentially of a major fraction of copper and a minor fraction of tin; and
  - (3) an active metal which can form a chemical bond with the abrasive grains on sintering;
- (b) mixing the particulate ingredients to form a uniform composition;
- (c) placing the uniform composition into a mold of preselected shape;
- (d) compressing the mold to a pressure in the range of about 345 - 690 MPa for a duration effective to form a molded article;
- (e) heating the molded article to a temperature in the range of about 500 - 900°C for a duration effective to sinter the metal

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component and active metal to a sintered bond, thereby integrating the abrasive grains and sintered bond into a grain-reinforced composite; and

(f) cooling the grain-reinforced composite to form the abrasive tool.

The present invention can be applied to straight, circular, monolithic abrasive wheels. The term "straight" means that the axial thickness of the wheel is uniform at all radii from the radius of the arbor hole to the outer radius of the wheel. An important application intended for these wheels is slicing thin sections such as wafers and pucks of inorganic substances with precision and reduced kerf loss. Often superior results are achieved by operating the wheel at high cutting speeds, *i.e.,* velocity of the abrasive surface in contact with the work piece. Such performance criteria and operating conditions are usually attained using wheels of extremely small, uniform thickness and large diameter. Hence, preferred wheels of this invention prominently feature a characteristically high aspect ratio . Aspect ratio is defined as the ratio of the outer diameter of the wheel divided by the axial cross section dimension, that is, the thickness of the wheel. The aspect ratio should be about 20 - 6000, preferably about 100 - 1200, and more preferably, about 250 - 1200 to 1.

The uniformity of wheel thickness is held to a tight tolerance to achieve desired cutting performance. Preferably, the uniform thickness is in the range of about 20 - 2,500 μm, more preferably, about 100-500 μm, and most preferably, about 100-200 μm. Variability in thickness of less than about 5 μm is preferred. Typically, the diameter of the arbor hole is about 12-90 mm and the wheel diameter is about 50 - 120 mm.

The term "monolithic" means that the abrasive wheel material is a uniform composition completely from the radius of the arbor hole to the radius of the wheel. That is, basically the whole body of the monolithic wheel is an abrasive disk comprising abrasive grains embedded in a sintered bond. The abrasive disk does not have an integral, non-abrasive portion for structural support of the abrasive portion, such as a metal core on which the abrasive portion of a grinding wheel is affixed, for example.

Basically, the abrasive disk of this invention comprises three ingredients, namely, abrasive grains, a metal component and an active metal component. The metal component and the active metal together form a sintered bond to hold the abrasive grains in the desired shape of the wheel. The sintered bond is achieved by subjecting the components to suitable sintering conditions. The term "active metal" means an element or compound that is capable of reacting with the surface of the abrasive grains on sintering. Hence, the active metal chemically bonds to abrasive grains. Furthermore, the active metal is present in an amount effective to integrate the grains and sintered bond into a grain-reinforced composite. Consequently, by judiciously choosing suitably high rigidity as well as high hardness abrasive grains, the overall stiffness of the abrasive-sintered bond matrix is enhanced by the active metal component chemically bonding to the abrasive grains during sintering.

A primary consideration for selecting the abrasive grain is that the abrasive substance should be harder than the material to be cut. Usually the abrasive grains of thin abrasive wheels will be selected from very hard substances because these wheels are typically used to abrade extremely hard materials such as alumina-titanium carbide. As mentioned, it is important that the abrasive substance also should have a sufficiently high rigidity to reinforce the structure of the bond. This additional criterion for selection of the abrasive substance normally devolves to assuring that the elastic modulus of the abrasive substance is higher, and preferably, significantly higher than that of the sintered bond. Representative hard abrasive substances for use in this invention are so-called superabrasives such as diamond and cubic boron nitride, and other hard abrasives such as silicon carbide, fused aluminum oxide, microcrystalline alumina, silicon nitride, boron carbide and tungsten carbide. Mixtures of at least two of these abrasives can also be used. Diamond is preferred.

The abrasive grains are usually utilized in fine particle form. The particle size of the grains for wheels of up to about 120 mm diameter generally should

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be in the range of about 0.5 - 100 μm, and preferably, about 10-30 μm. The grains size for wheels of larger diameter can be proportionately larger.

The metal component of this invention can be a single metal element or a mixture of multiple elements. Representative elements suitable for use in this invention include copper, tin, cobalt, iron, nickel, silver, zinc, antimony and manganese. Examples of mixtures include copper-tin, copper-tin-iron-nickel, copper-zinc-silver, copper-nickel-zinc, copper-nickel-antimony. Metal compounds such as cobalt-tungsten carbide, and nickel-copper-antimony-tantalum carbide, and alloys containing non-metals can also be used. The non-metallic component typically enhances hardness of the metal or depresses the metal melting temperature, which helps lower sintering temperature and thereby avoids damage of diamond from exposure to high temperatures. Examples of such non-metal-containing compounds and alloys include nickel-copper-manganese-silicon-iron, and nickel-boron-silicon, The metal component generally is provided as a small particle size powder. The powder particles of a multiple element metal component can either be of individual elements, pre-alloys or a mixture of both.

Due to the active metal component, the sintered bond chemically attaches to the abrasive grains rather than merely embraces them. Hence, the grains of the novel, actively bonded, thin abrasive wheel can be presented to the work piece with greater exposure than could grains of non-actively bonded wheels. Additionally, softer sintered bond compositions can be used. These features provide the advantage that the wheel will cut more freely with less tendency to load, and therefore, to operate at reduced power consumption. Copper-tin is a preferred composition for a metal component that produces a relatively soft bond.

For a metal component of copper-tin, generally a major fraction (*i.e.,* > 50 wt%) is copper and a minor fraction (*i.e.,* < 50 wt%) is tin. Preferably the copper-tin composition consists essentially of about 50-90 wt% copper and about 10-40 wt% tin; more preferably, about 70-90 wt% copper and about 10-30 wt% tin; and most preferably about 70 - 75 wt% copper and 25-30 wt% tin. As the below description of the preparation of the novel actively bonded thin abrasive wheels will explain, the metal component is usually supplied to the wheel manufacturing process in fine particle form.

The active metal component is chosen for compatibility with both the metal component of the sintered bond and the abrasive grains. That is, under sintering conditions, the active metal should densify with the metal component to form a strong sintered bond, and it should react with the surface of the abrasive grains to form a chemical bond therewith. Selection of the active metal component can depend largely on the composition of the metal component, the composition of the abrasive grains, and sintering conditions. Representative materials for the active metal component are titanium, zirconium, hafnium, chromium, tantalum and mixtures of at least two of them. In a mixture, the active component metals can be supplied as individual metal particles or as alloys. Titanium is preferred, especially in connection with copper-tin metal component and diamond abrasive.

The active component can be added either in elemental form or as a compound of metal and non-active component elements. Elemental titanium reacts with water and or oxygen at low temperature to form titanium dioxide and thus becomes unavailable to react with abrasive during sintering. Therefore, adding elemental titanium is less preferred when water or oxygen is present. If titanium is added in compound form, the compound should be capable of dissociation to elemental form prior to the sintering step to permit the titanium to react with the abrasive. A preferred compound form of titanium for use in this invention is titanium hydride, TiH_2, which is stable up to about 500°C. Above about 500°C, titanium hydride dissociates to titanium and hydrogen.

Both the metal component constituents and active metal components preferably are incorporated into the bond composition in particle form. The particles should have a small particle size to help achieve a uniform concentration throughout the sintered bond and optimum contact with the abrasive grains during sintering, and to develop good bond strength to the grains. Fine particles of maximum dimension of about 44 μm are preferred.

Particle size of the metal powders can be determined by filtering the particles through a specified mesh size sieve. For example, nominal 44 µm maximum particles will pass through a 325 U.S. standard mesh sieve.

In a preferred embodiment, the actively bonded thin abrasive wheel comprises sintered bond of about 45 - 75 wt% copper, about 20 - 35 wt% tin and about 5 - 20 wt% active metal, the total adding to 100 wt%. In a particularly preferred embodiment, the active metal is titanium. As mentioned, preference is given to incorporating the titanium component in the form of titanium hydride. The slight difference between the molecular weight of elemental titanium and titanium hydride usually can be neglected. However, for sake of clarity it is noted that the compositions stated herein refer to the titanium present, unless specifically indicated otherwise.

The novel abrasive wheel is basically produced by a densification process of the so-called "cold press" or "hot press" types. In a cold press process, occasionally referred to as "pressureless sintering", a blend of the components is introduced into a mold of desired shape and a high pressure is applied at room temperature to obtain a compact but friable molded article. Usually the high pressure is above about 300 MPa. Subsequently, pressure is relieved and the molded article is removed from the mold then heated to sintering temperature. The heating for sintering normally is done while the molded article is pressurized in an inert gas atmosphere to a lower pressure than the pre-sintering step pressure , *i.e.,* less than about 100 MPa, and preferably less than about 50 MPa. Sintering can also take place under vacuum. During this low pressure sintering, the molded article, such as a disk for a thin abrasive wheel, advantageously can be placed in a mold and/or sandwiched between flat plates.

In a hot press process, the blend of particulate bond composition components is put in the mold, typically of graphite, and compressed to a high pressure as in the cold process. However, an inert gas is utilized and the high pressure is maintained while the temperature is raised thereby achieving densification while the preform is under pressure.

An initial step of the abrasive wheel process involves packing the components into a shape forming mold. The components can be added as a uniform blend of separate abrasive grains, metal component constituent particles and active metal component constituent particles. This uniform blend can be formed by using any suitable mechanical blending apparatus known in the art to blend a mixture of the grains and particles in preselected proportion. Illustrative mixing equipment can include double cone tumblers, twin-shell V-shaped tumblers, ribbon blenders, horizontal drum tumblers, and stationary shell/internal screw mixers.

The copper and tin can be pre-alloyed and introduced as bronze particles. Another option includes combining and then blending to uniformity a stock bronze particulate composition, additional copper and/or tin particles, active metal particles and abrasive grains.

In a basic embodiment of the invention, the abrasive grains are uncoated prior to sintering the bond. That is, the abrasive grains are free of metal on their surface. Another embodiment calls for pre-coating the abrasive grains with a layer comprising all or a portion of the active metal component prior to mechanically blending all of the components. This technique can enhance chemical bond formation between abrasive grains and active metal during sintering.

The layer can be of molecular thickness, for example as can be obtained by chemical vapor deposition or physical vapor deposition, or of macromolecular thickness. If a molecular thickness is used, it is recommended to supplement the amount of active metal in the pre-coating with additional active metal in the mixture of grains and bond composition components. Usually a molecular thickness of pre-coating does not alone possess a sufficient amount of the active metal to attain the beneficial results that can be achieved by this invention.

A macromolecular thickness coating can be achieved by (A) mixing to uniform composition a fine powder of the active metal component and an effective amount of a fugitive liquid binder to form a tacky paste; (B) mixing the abrasive grains with the adhesive paste to wet at least a major fraction of the grain surface area with the adhesive paste; and (C) drying the liquid binder, usually with heat, to leave a residue of the active metal powder particles mechanically attached to the abrasive grains. The purpose of mechanical attachment is to maintain the active metal particles in proximity to the grains at least until sintering when the chemical bonding will render the attachment permanent. Any conventional fugitive liquid binder can be used for the paste. The term "fugitive" means that the liquid binder has the ability to vacate the bond composition at elevated temperature, preferably below sintering temperature and without adversely impacting the sintering process. The binder should be sufficiently volatile to substantially completely evaporate and/or pyrolyze during sintering without leaving a residue that might interfere with the function of the bond. Preferably the binder will vaporize below about 400°C. The binder can be blended with the particles by many methods well known in the art.

The mixture of components to be charged to the shape forming mold can include minor amounts of optional processing aids such as paraffin wax, "Acrowax", and zinc stearate which are customarily employed in the abrasives industry.

Once the uniform blend is prepared, it is charged into a suitable mold. In a preferred cold press sintering process, the mold contents can be compressed with externally applied mechanical pressure at ambient temperature to about 345 - 690 MPa. A platen press can be used for this operation, for example. Compression is usually maintained for about 5-15 seconds, after which pressure is relieved. The mold contents are next raised to sintering temperature, which should be high enough to cause the bond composition to densify but not melt substantially completely. The sintering temperature should be at least about 500°C. Heating should take place in an inert atmosphere, such as under low absolute pressure vacuum or under blanket of inert gas. It is important to select metal bond and active metal components which do not require sintering at such high temperatures that abrasive grains are adversely affected. For example, diamond begins to graphitize above about 1100°C. Therefore, sintering of diamond abrasive wheels should be designed to occur safely below this temperature, preferably below about 950°C, and more preferably below about 900°C. Sintering temperature should be held for a duration effective to sinter the bond components and to simultaneously react the active metal with the abrasive grains. Sintering temperature typically is maintained for about 30 - 120 minutes.

In a preferred hot press process, conditions are generally the same as for cold pressing except that pressure is maintained until completion of sintering. In either pressureless sintering or hot pressing, after sintering, the molds are lowered to ambient temperature and the sintered products are removed. The products are finished by conventional methods such as lapping to obtain desired dimensional tolerances.

The above mentioned sintering and bonding thus integrates the abrasive grains into the sintered bond so as to form a grain-reinforced composite. To facilitate formation of the grain-reinforced composite as well as to provide well exposed abrasive, it is preferred to use about 2.5 - 50 vol. % abrasive grains and a complemental amount of sintered bond in the sintered product.

The preferred abrasive tool according to this invention is an abrasive wheel. Accordingly, the typical mold shape is that of a thin disk. A solid disk mold can be used, in which case after sintering a central disk portion can be removed to form the arbor hole. Alternatively, an annular shaped mold can be used to form the arbor hole *in situ*. The latter technique avoids waste due to discarding the abrasive-laden central portion of the sintered disk.

Upon successful formation of a grain-reinforced composite structure, the abrasive grains will contribute to the stiffness of the wheel. Hence, as stated above, it is important that the abrasive be selected not only for traditional characteristics of hardness, impact resistance and the like, but also for stiffness properties as determined by elastic modulus, for example. While not wishing to be bound by a particular theory, it is believed that very rigid abrasive particles integrated into the sintered bond by virtue of chemical bonding with the active metal component contribute significantly to the stiffness of the composite. This contribution is thought to occur because stress loads on the composite during operation are effectively transferred to the intrinsically very stiff, abrasive grains. It is thus possible by practice of this invention to obtain straight, actively bonded thin abrasive wheels that are stiffer than conventional wheels of equal thickness. The novel wheels are useful for providing more precise cuts and less chipping with no further sacrifice of kerf loss relative to traditional straight wheels.

The stiffness of the novel abrasive wheel should be enhanced considerably relative to conventional wheels. In a preferred embodiment, the elastic modulus of the actively bonded abrasive wheel is higher than the elastic modulus of the sintered bond components alone (*i.e.*, metal component plus active metal component free of abrasive grains) and also is at least about 100 GPa and preferably at least about 150 GPa. In another preferred embodiment, the elastic modulus of the wheel is at least about two times the elastic modulus of the sintered bond free of abrasive grains.

This invention is now illustrated by examples of certain representative embodiments thereof, wherein, unless otherwise indicated, all parts, proportions and percentages are by weight and particle sizes are stated by U.S. standard sieve mesh size designation. All units of weight and measure not originally obtained in SI units have been converted to SI units.

Example 1

Copper powder (<400 mesh), tin powder (<325 mesh) and titanium hydride (<325 mesh) were combined in proportions of 59.63% Cu, 23.85% Sn and 16.50% TiH_2. This bond composition was passed through a 165 mesh stainless steel screen to remove agglomerates and the screened mixture was thoroughly blended in a "Turbula" brand mixer (Glen Mills, Inc., Clifton, New Jersey) for 30 minutes. Diamond abrasive grains (15-25 µm) from GE Superabrasives, Worthington, Ohio, were added to the metal blend to form a mixture containing 18.75 vol. % of diamond. This mixture was blended in a Turbula mixer for 1 hour to obtain a uniform abrasive and bond composition.

The abrasive and bond composition was placed into a steel mold having a cavity of 121.67 mm outer diameter, 6.35 mm inner diameter and uniform depth of 0.81 mm. A "green" wheel was formed by compacting the mold at ambient temperature under 414 MPa (4.65 tons/cm^2) for 10 seconds. The green wheel was removed from the mold then heated to 850°C under vacuum for 2 hours between horizontal, flat plates with a 660 g weight set on the upper plate. The hot sintered product was permitted to gradually cool to 250°C then it was rapidly cooled to ambient temperature. The wheel was ground to final size by conventional methods, including "truing" to a preselected run out, and initial dressing under conditions shown in Table I.

The finished wheel size was 114.3 mm outer diameter, 69.88 mm inner diameter (arbor hole diameter) and 0.178 mm thickness.

Table I

Truing Conditions Examples 1-2

Trued Wheel	
Speed	5593 rev./min.
Feed rate	100 mm/min.
Exposure from flange	3.68 mm
Truing Wheel	model no. 37C220-H9B4
Composition	silicon carbide
Diameter	112.65 mm
Speed	3000 rev./min.
Traverse rate	305 mm/min.
No. of passes	
at 2.5 μm	40
at 1.25 μm	40
Initial Dressing	
Wheel speed	2500 rev./min.
Dressing stick	type 37C500-GV
Dressing stick width	12.7 mm
Penetration	2.54 mm
Feed rate	100mm/min.
No. of passes	12.00

Example 2 and Comparative Example 1

The novel wheel manufactured as described in Example 1 and a conventional, commercially available wheel of same size (Comp. Ex. 1) were used to cut multiple slices through a 150 mm long x 150 mm wide x 1.98 mm thick block of type 3M-310 (Minnesota Mining and Manufacturing Co., Minneapolis, Minnesota) alumina-titanium carbide glued to a graphite substrate. The Comp. Ex. 1 wheel composition was 18.9 vol. % 15/25 µm diamond grains in a bond of 53.1 wt% cobalt, 23.0 wt% nickel, 12.7 wt% silver, 5.4 wt% iron, 3.4 wt% copper and 2.4 wt% zinc. Before each slice, the wheels were dressed as described in Table I except that a single dressing pass and a 19 mm width dressing stick (12.7 mm for Comp. Ex. 1) was used. In each test the abrasive wheels were mounted between two metal supporting spacers of 106.93 mm outer diameter. Wheel speed was 7500 rev./min. (9000 rev./min. for Comp. Ex. 1) and a feed rate of 100 mm/min. and cut depth of 2.34 mm were utilized. The cutting was cooled by a flow of 56.4 L/min. 5% rust inhibitor stabilized demineralized water discharged through a 1.58 mm x 85.7 mm rectangular nozzle at a pressure of 275 kPa.

Cutting results are shown in Table II. The novel wheel performed well against all cutting performance criteria. The Comp. Ex. 1 wheel needed to operate at 20% higher rotations peed and drew about 45% higher power than the novel wheel (about 520 W vs. 369 W).

Table II

	Slices		Cum. Length sliced	Wheel Wear			Workpiece		Cut Straightness	Spin Power Draw
	No.	Cum. No.	m	Radial µm	Cum. µm	factor[1] µm/m	Max Chip µm	Avg Chip µm	µm	W
Ex. 1	9.00	9.00	1.35	5.08	5.08	3.70	8.00	<5	<5	
	9.00	18.00	2.70	0.00	5.08	0.00	9.00	5.00	<5	
	9.00	27.00	4.05	0.00	5.08	0.00	11.00	<5	<5	368-296
	9.00	36.00	5.40	10.16	15.24	7.40	6.00	<5	<5	
	9.00	45.00	6.75	2.54	17.78	1.90	10.00	5.00	<5	
	9.00	54.00	8.10	2.54	20.32	1.90	11.00	5.00	<5	312-368
	9.00	63.00	9.45	10.16	30.48	7.40	8.00	<5	<5	
	9.00	72.00	10.8	2.54	33.02	1.90	9.00	<5	<5	
	9.00	81.00	12.0	2.54	35.56	<0.5	9.00	<5	<5	376-328
Comp.Ex. 1	9.00	9.00	1.35	5.08	5.08	3.70	11.00	<5	<5	520-536
	9.00	18.00	2.70	10.16	15.24	7.40				
	9.00	27.00	4.05	5.08	20.32	3.70				
	9.00	36.00	5.40	2.54	22.86	1.90	10.00	<5	<5	
	9.00	45.00	6.75	5.08	27.94	3.70				
	9.00	54.00	8.10	2.54	30.48	1.90				
	9.00	63.00	9.45	5.08	35.56	3.70	14.00	<5	<5	560-576

[1] Wear factor = Radial wheel wear divided by length of workpiece sliced

Examples 3 and 4, and Comparative Examples 2-8

The stiffness of grain reinforced abrasive wheel compositions was tested. A variety of fine metal powders with and without diamond grains were combined in proportions shown in Table III and mixed to composition uniformity as in Example 1. Tensile test specimens were produced by compressing the compositions in dogbone-shaped molds at ambient temperature under a pressure of about 414-620 MPa (30-45 Tons/in^2) for about 5-10 seconds and then sintered under vacuum as described in Example 1.

The test specimens were subjected to sonic and standard tensile modulus measurements on an Instron tensile test machine. Results are shown in Table III. Elastic modulus of the grain reinforced samples (Ex. 3 and 4) exceeded 150 GPa. The increased concentration of diamond in Ex. 4 boosted modulus significantly which confirms that the diamond became integrated into the composition. In contrast, Comp. Ex. 2 revealed that the same bond composition without grain reinforcement due to absence of diamond dramatically reduced stiffness. Similarly, Comp. Ex. 3 demonstrates that the diamond embedded in a bronze bond composition without an active component provides relatively poor stiffness.

In Comp. Ex. 4, diamond grains formerly commercially available from General Electric Co. which were stated by the manufacturer to be surface coated with about 1-2 μm thickness of titanium were used. Stiffness improved slightly compared to having no active component present (Comp. Ex. 3), but fell far short of the operative example compositions. Suspected reasons for the reduced effectiveness are that too small amount of active component was present, that the titanium on the surface was in carbide form prior to sintering which rendered the titanium less compatible with the other metal components, and/or that non-carbide titanium on the grains was oxidized.

Comp. Exs. 5 and 7 demonstrate that conventional thin diamond wheels with different compositions of copper/tin/nickel/iron bonds have moduli of only about 100 GPa. Comp. Exs. 6 and 8 correspond to the wheel compositions of Comp. Exs. 5 and 7 without diamond grains. These examples show that stiffness of the bond compositions either with or without diamond was about the same. This confirms the expectation that the active metal component-free bond does not integrate the diamond into the bond so as to reinforce the structure.

Table III

	Ex. 3	Ex. 4	Comp. Ex. 2	Comp. Ex. 3	Comp. Ex. 4	Comp. Ex. 5	Comp. Ex. 6	Comp. Ex. 7	Comp. Ex. 8
Copper, wt%	59.50	59.50	59.50	80.00	80.00	70.00	70.00	62.00	62.00
Tin, wt%	24.00	24.00	24.00	20.00	20.00	9.10	9.10	9.20	9.20
Titanium, wt%	16.50	16.50	16.50						
Nickel, wt%						7.50	7.50	15.30	15.30
Iron, wt%						13.40	13.40	13.50	13.50
Diamond, vol. %	18.80	30.00		18.80	18.8*	18.80		18.80	
Sonic Modulus, GPa	176.00	220.00		67.00	80.00	95.00		99.00	
Tensile Modulus, GPa	276.00		110.00	60.00	84.00		106.00	103.00	95.00

* diamond coated with ca. 1-2 μm titanium

Although specific forms of the invention have been selected for illustration in the examples, and the preceding description is drawn in specific terms for the purpose of describing these forms of the invention, this description is not intended to limit the scope of the invention which is defined in the claims.

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Claims

1. An abrasive wheel comprising a straight, grain-reinforced abrasive disk having a uniform width in the range of about 20 - 2,500 μm, consisting essentially of about 2.5- 50 vol. % abrasive grains and a complemental amount of a bond comprising a metal component and an active metal which forms a chemical bond with the abrasive grains on sintering, the active metal and abrasive grains being present in an amount effective to produce a grain-reinforced abrasive disk having an elastic modulus value at least 10% higher than the elastic modulus value of an abrasive disk of same composition but free of active metal.

2. The abrasive wheel of claim 1 in which the abrasive grains are about 0.5 - 100 μm in size and the grain-reinforced abrasive disk has an elastic modulus value of at least about 100 GPa.

3. The abrasive wheel of claim 2 in which the elastic modulus value is at least about twice as high as the elastic modulus value of the same sintered bond composition free of abrasive grains.

4. The abrasive wheel of claim 3 in which the abrasive disk consists essentially of about 15 - 30 vol. % of abrasive grains.

5. The abrasive wheel of claim 1 in which the metal component is selected from the group consisting of copper, tin, cobalt, iron, nickel, silver, zinc, antimony, manganese, metal carbide and alloys of at least two of them.

6. The abrasive of claim 1 in which the metal component comprises a metal alloy or metal compound containing a material selected from the group consisting of boron, silicon, and compounds and combinations thereof.

7. The abrasive wheel of claim 4 in which the active metal is selected from the group consisting of titanium, zirconium, hafnium, chromium, tantalum, and a mixture of at least two of them.

8. The abrasive wheel of claim 7 in which the abrasive grains are free of active metal coating.

9. The abrasive wheel of claim 7 in which the abrasive grains are coated with a macromolecular thickness layer of metal.

10. The abrasive wheel of claim 1 which is monolithic.

11. The abrasive wheel of claim 5 in which the sintered bond comprises

(a) about 45 - 75 wt% copper;

(b) about 20 - 35 wt% tin; and

(c) about 5 - 20 wt% active metal

in which the total of (a), (b) and (c) is 100 wt%.

12. The abrasive wheel of claim 11 in which the active metal is selected from the group consisting of titanium, zirconium, hafnium, chromium, tantalum, and a mixture of at least two of them.

13. The abrasive wheel of claim 12 in which the active metal is titanium.

14. The abrasive wheel of claim 1 in which abrasive grains are of an abrasive selected from the group consisting of diamond, cubic boron nitride, silicon carbide, fused aluminum oxide, microcrystalline alumina, silicon nitride, boron carbide, tungsten carbide and mixtures of at least two of them.

15. The abrasive wheel of claim 14 in which the abrasive grains are diamond.

16. The abrasive wheel of claim 1 consisting essentially of the abrasive disk which has a circumferential rim of diameter of about 40-120 mm, which defines an axial arbor hole of about 12-90 mm, which has uniform width in the range of about 100 - 500 μm and which consists essentially of diamond grains and a sintered bond comprising about 59.5 wt% copper, 24 wt% tin and 16.5 wt% titanium.

17. The abrasive wheel of claim 16 in which the uniform width is in the range of about 100-200 μm.

18. An abrasive wheel comprising a straight, grain-reinforced abrasive disk having a uniform width and an aspect ratio of about 20-6000 to 1, consisting essentially of about 2.5 - 50 vol. % abrasive grains and a complemental amount of a bond comprising a metal component and an active metal which forms a chemical bond with the abrasive grains on sintering, the active metal and abrasive grains being present in an amount effective to produce a grain-reinforced abrasive disk having an elastic modulus value at least 10% higher than the elastic modulus value of an abrasive disk of same composition but free of active metal.

19. A method of cutting a work piece comprising the step of contacting the work piece with an abrasive wheel comprising a straight, grain-reinforced abrasive disk having a uniform width in the range of about 20 - 2,500 μm, consisting essentially of about 2.5- 50 vol. % abrasive grains and a complemental amount of a bond comprising a metal component and an active metal which forms a chemical bond with the abrasive grains on sintering, the active metal and abrasive grains being present in an amount effective to produce a grain-reinforced abrasive disk having an elastic modulus value of at least 10% higher than the elastic modulus value of an abrasive disk of same composition but free of active metal.

20. The method of claim 19 in which the abrasive disk further comprises a circumferential rim of diameter of about 40-120 mm, and an axial arbor hole of about 12-90 mm, and in which the metal component is selected from the group consisting of copper, tin, cobalt, iron, nickel, silver, zinc, antimony, manganese, metal carbide and alloys of at least two of them, and the active metal is selected from the group consisting of titanium, zirconium, hafnium, chromium, tantalum, and a mixture of at least two of them, and the abrasive grains are about 0.5 - 100 μm in size, and the grain-reinforced abrasive disk has an elastic modulus of at least about 100 GPa and which modulus is at least about twice as high as the elastic modulus of the sintered bond free of abrasive grains.

21. The method of claim 20 in which the metal component comprises a metal alloy or metal compound containing a material selected from the group consisting of boron, silicon, and compounds and combinations thereof.

22. The method of claim 20 in which

the circumferential rim diameter is about 50-120 mm, the uniform width is in the range of about 100- 500 μm, and

the abrasive disk consists essentially of diamond grains and a sintered bond consisting essentially of (a) about 45 - 75 wt% copper; (b) about 20 - 35 wt% tin; and (c) about 5 - 20 wt% active metal, in which the total of (a), (b) and (c) is 100 wt%.

23. The method of claim 19 in which the work piece is alumina-titanium carbide.

24. A method of making an abrasive tool comprising the steps of

(a) providing preselected proportions of particulate ingredients comprising

(1) abrasive grains;

(2) a metal component consisting essentially of a major fraction of copper and a minor fraction of tin; and

(3) an active metal which is chemically reactive with the abrasive grains under sintering conditions;

(b) mixing the particulate ingredients to form a uniform composition;

(c) placing the uniform composition into a mold of preselected shape;

(d) compressing the mold to a pressure in the range of about 345 - 690 MPa for a duration effective to form a molded article;

(e) heating the molded article to a temperature in the range of about 500 - 900°C for a duration effective to sinter the metal component and active metal to a sintered bond, thereby integrating the abrasive grains and sintered bond into a grain-reinforced composite; and

(f) cooling the grain-reinforced composite to form the abrasive tool.

25. The method of claim 24 which further comprises the step of reducing the pressure on the molded article to a pressure less than about 100 MPa after the compressing step and maintaining the pressure at less than about 100 MPa during the heating step.

26. The method of claim 25 in which the molded article is reduced to and maintained during the heating step at a pressure of about 10-40 MPa.

27. The method of claim 25 in which the abrasive tool is a disk having a uniform width in the range of about 100-500 μm, a circumferential rim of diameter of about 50-120 mm and which disk defines an axial arbor hole of about 12-90 mm.

28. The method of claim 27 further comprising the steps of removing the disk from the mold after the compressing step and sandwiching the disk between flat plates biased against the disk during the heating step.

29. The method of claim 27 in which the disk has uniform width in the range of about 100 - 200 µm.

30. The method of claim 20 in which the heating step occurs while the molded article is maintained at the pressure of the compressing step.

31. The method of claim 24 in which the abrasive grains are provided free of active metal coating.

32. The method of claim 24 in which the abrasive grains are coated with a macromolecular thickness layer of metal prior to the mixing step.

33. The method of claim 24 in which the particulate ingredients comprise (a) about 45 - 75 wt% copper; (b) about 20 - 35 wt% tin; and (c) about 5 - 20 wt% active metal selected from the group consisting of titanium, zirconium, hafnium, chromium, tantalum and a mixture of at least two of them, the total of (a), (b) and (c) being 100 wt%.

34. The method of claim 33 in which the providing step further comprises

(i) mixing to uniform composition a fine powder of the active metal component and an effective amount of a liquid binder to form a tacky paste;

(ii) mixing the abrasive grains with the adhesive paste to wet at least a major fraction of the grain surface area with the adhesive paste; and

(iii) drying the liquid binder effectively to leave a residue of the active metal powder particles mechanically attached to the abrasive grains.

35. The method of claim 24 in which the abrasive grains comprise about 20-50 vol. % abrasive grains of particulate ingredients, and consist essentially of an abrasive selected from the group consisting of diamond, cubic boron nitride, silicon carbide, fused aluminum oxide, microcrystalline alumina, silicon nitride, boron carbide, tungsten carbide and mixtures of at least two of them.

36. The method of claim 35 in which the abrasive grains are diamond.

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[54]发明名称 具有活性粘合的超级磨轮

[57]摘要

一种由硬而刚性的磨粒与烧结粘合剂形成的直的单块薄磨轮具有优良硬挺性，所述烧结粘合剂包括金属组分和活性金属组分。所述金属组分可选自许多可烧结的金属组分。所述活性金属组分是在烧结条件下能与磨粒反应形成键合的金属，其含量实际使磨粒和烧结粘合剂结合成磨粒增强复合物。较好为金刚石磨料、铜/锡/钛烧结粘合剂磨轮。这种磨轮用于电子工业的研磨操作，如切割硅晶片和氧化铝－碳化钛圆盘。该新磨轮的硬挺性高于常规的单块直磨轮，因此在不增加磨轮厚度和随之增加切口损耗的情况下改进切割精度并减少切屑。

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权 利 要 求 书

1. 一种磨轮，它包括均匀宽度约 20-2500 微米的直的磨粒增强磨盘，它主要由约 2.5-50 体积%磨粒和余量的粘合剂组成，所述粘合剂包括一种金属组分和一种经烧结与磨粒形成化学键的活性金属，所述活性金属和磨粒的含量实际使形成的磨粒增强磨盘的弹性模量值比同样组成但无活性金属的磨盘的弹性模量值至少高 10%。

2. 如权利要求 1 所述的磨轮，其特征在于所述磨粒的粒度约为 0.5-100 微米，所述磨粒增强磨盘的弹性模量值至少约 100GPa。

3. 如权利要求 2 所述的磨轮，其特征在于所述弹性模量值是无磨粒的同样烧结粘合剂组合物的弹性模量值的至少约两倍。

4. 如权利要求 3 所述的磨轮，其特征在于所述磨盘主要由约 15-30 体积%的磨粒组成。

5. 如权利要求 1 所述的磨轮，其特征在于所述金属组分选自铜、锡、钴、铁、镍、银、锌、锑、锰、金属碳化物和至少两种这种金属的合金。

6. 如权利要求 1 所述的磨轮，其特征在于所述金属组分包括金属合金或者含选自硼、硅及其化合物的材料的金属化合物和其混合物。

7. 如权利要求 4 所述的磨轮，其特征在于所述活性金属选自钛、锆、铪、铬、钽以及至少两种这些金属的混合物

8. 如权利要求 7 所述的磨轮，其特征在于所述磨粒无活性金属涂层。

9. 如权利要求 7 所述的磨轮，其特征在于所述磨粒涂覆金属的大分子厚度涂层。

10. 如权利要求 1 所述的磨轮，其特征在于所述磨轮是单块磨轮。

11. 如权利要求 5 所述的磨轮，其特征在于所述烧结粘合剂包括：

(a)约 45-75 重量%铜；

(b)约 20-35 重量%锡；和

(c)约 5-20 重量%活性金属；

其中(a)、(b)、(c)之和为 100 重量%。

12. 如权利要求 11 所述的磨轮，其特征在于所述活性金属选自钛、锆、铪、铬、钽及其至少两种的混合物。

13. 如权利要求 12 所述的磨轮，其特征在于所述活性金属是钛。

14. 如权利要求 1 所述的磨轮，其特征在于所述磨粒选自金刚石、立方氮化硼、碳化硅、熔凝氧化铝、微晶氧化铝、氮化硅、碳化硼、碳化钨及其至少两种的混合物。

15. 如权利要求 14 所述的磨轮，其特征在于所述磨粒是金刚石。

16. 如权利要求 1 所述的磨轮，它主要由圆周直径约 40-120mm 的磨盘所组成，该磨盘具有约 12-90mm 的芯轴孔，具有约 100-500 微米范围内的均匀宽度，该磨盘主要由金刚石磨粒和含约 59.5 重量％铜、24 重量％锡和 16.5 重量％钛的烧结粘合剂所组成。

17. 如权利要求 16 所述的磨轮，其特征在于所述均匀宽度的范围约为 100-200 微米。

18. 一种磨轮，它包括径厚比约 20-6000：1 的宽度均匀的直的磨粒增强磨盘，它主要由约 2.5-50 体积％磨粒和余量的粘合剂组成，所述粘合剂包括一种金属组分和一种经烧结与磨粒形成化学键的活性金属，所述活性金属和磨粒的含量实际使形成的磨粒增强磨盘的弹性模量值比同样组成但无活性金属的磨盘的弹性模量值至少高 10％。

19. 一种工件的切割方法，它包括使工件与磨轮接触的步骤，所述磨轮包括均匀宽度约 20-2500 微米的直的磨粒增强磨盘，它主要由约 2.5-50 体积％磨粒和余量的粘合剂组成，所述粘合剂包括一种金属组分和一种经烧结与磨粒形成化学键的活性金属，所述活性金属和磨粒的含量实际使制得的磨粒增强磨盘的弹性模量值比同样组成但无活性金属的磨盘的弹性模量值至少高 10％。

20. 如权利要求 19 所述的方法，其特征在于所述磨盘还包括约 40-120mm 的圆周直径和约 12-90mm 的芯轴孔，并且所述金属组分选自铜、锡、钴、铁、镍、银、锌、锑、锰、金属碳化物和至少两种这些金属的合金，所述活性金属选自钛、锆、铪、铬、钽及其至少两种的混合物，磨粒的粒度约为 0.5-100 微米，磨粒增强磨盘的弹性模量至少约 100GPa，该模量是无磨粒的烧结粘合剂的弹性模量的至少约两倍。

21. 如权利要求 20 所述的方法，其特征在于所述金属组分包括金属合金，或者含选自硼、硅及其化合物的材料的金属化合物或其混合物。

22. 如权利要求 20 所述的方法，其特征在于所述圆周直径约为 50-120 毫米，均匀宽度范围约为 100-500 微米，并且磨盘主要由金刚石磨粒和含(a)约 45-75 重量％铜、(b)约 20-35 重量％锡、和(c)约 5-20 重量％活性金属的烧结

粘合剂所组成，其中(a)、(b)和(c)之和为100重量%。

23.如权利要求19所述的方法，其特征在于所述工件是氧化铝-碳化钛。

24.一种磨具的制造方法，它包括：

(a)提供预定比例的颗粒组分，包括：

(1)磨粒；

(2)主要由主要量的铜和次要量的锡组成的金属组分；和

(3)在烧结条件下可与磨粒发生化学反应的活性金属；

(b)将该颗粒组分混合成均匀的组合物；

(c)将该均匀的组合物置于预定形状的模具中；

(d)向该模具施加约345-690MPa的压力，施压的时间足以形成成型制品；

(e)将该成型制品加热至约500-900℃的温度，加热的时间足以将该金属组分和活性金属烧结成烧结粘合剂，从而将磨粒和烧结粘合剂结合成磨粒增强复合物；和

(f)冷却该磨粒增强复合物，形成磨具。

25.如权利要求24所述的方法，它还包括压制步骤后将成型制品的压力降至低于约100MPa的压力并在加热步骤中将该压力保持在低于约100MPa的步骤。

26.如权利要求25所述的方法，其特征在于在加热步骤中间成型制品的压力降至并保持在约10-40MPa。

27.如权利要求25所述的方法，其特征在于所述磨具是一个磨盘，其均匀的宽度范围约为100-500微米，圆周直径约为50-120mm，并且带有一个约12-90mm的芯轴孔。

28.如权利要求27所述的方法，它还包括压制步骤后从模具中取出磨盘，在加热步骤中将磨盘夹在两片对磨盘有偏压的平板之间的步骤。

29.如权利要求27所述的方法，其特征在于圆盘的均匀宽度范围约为100-200微米。

30.如权利要求20所述的方法，其特征在于在保持压制步骤的压力的同时对成型制品实施加热步骤。

31.如权利要求24所述的方法，其特征在于提供的磨粒无活性金属涂层。

32.如权利要求24所述的方法，其特征在于混合步骤前磨粒涂覆有金属的大分子厚度涂层。

33. 如权利要求24所述的方法，其特征在于所述颗粒组分包括(a)约45-75重量%铜、(b)约20-35重量%锡、和(c)约5-20重量%活性金属，其中(a)、(b)和(c)之和为100重量%，所述活性金属选自钛、锆、铪、铬、钽及其至少两种的混合物。

34. 如权利要求33所述的方法，其特征在于提供步骤还包括：

(i) 将活性金属组分的细粉末和有效量的液体粘合剂混合成均匀的组合物，形成粘性糊浆；

(ii)将磨粒与该粘合剂糊浆混合在一起，使粘合剂糊浆至少湿润大部分磨粒表面；和

(iii)干燥液体粘合剂，使残留的活性金属粉末颗粒机械附着在磨粒上。

35. 如权利要求24所述的方法，其特征在于所述磨粒占颗粒组分的约20-50体积%，它主要由金刚石、立方氮化硼、碳化硅、熔凝氧化铝、微晶氧化铝、氮化硅、碳化硼、碳化钨及其至少两种的混合物所组成。

36. 如权利要求35所述的方法，其特征在于所述磨粒是金刚石。

说　　明　　书

具有活性粘合的超级磨轮

本发明涉及用于研磨很硬物件（如电子工业使用的物件）的薄磨轮。

在工业上很薄和很硬的磨轮是重要的。例如，在电子产品的制造中薄磨轮用于切下薄片和用于加工硅晶片和所谓氧化铝-碳化钛复合圆盘时的研磨操作。硅晶片一般用于集成电路，氧化铝-碳化钛圆盘用于制造悬浮薄膜磁头，以便记录和回放磁性储存的信息。美国专利 5,313,742 详细地描述了使用薄磨轮研磨硅晶片和氧化铝-碳化钛圆盘的方法，该专利文献全文在此引为参考。

如美国专利 5,313,742 所述，制造硅晶片和氧化铝-碳化钛圆盘要求尺寸精确的切割，对工件材料很少有浪费。较好的是进行这种切割的刀具应尽可能坚硬，并且尽可能薄，因为刀具越薄，产生的废料就越少；刀具越坚硬，切割就越直。但是，这些特性是相悖的，因为刀具越薄，其刚性就越低。

工业上已发展到使用单块磨轮（通常同轴排列在一根通过芯轴安装的轴上）。同轴排列的各个磨轮由不可压缩的耐久隔离件相互隔开。一般来说每个磨轮由其芯轴孔至周边具有均匀的轴向尺寸。尽管十分薄，但是这些磨轮的轴向尺寸大于所需的尺寸以便具有适当的硬挺度来进行十分精确的切割。但是，为了将产生的废料量限定在可接受的范围内，需要降低厚度。这使得磨轮的刚性低于理想的刚性。

因此常规的直磨轮比薄磨轮产生更多的工件废料，比较硬的磨轮产生更多切屑并且切割更不精确。美国专利 5,313,742 试图通过提高由芯轴孔径向朝外延伸的里面部分的厚度来改进同轴的直磨轮的性能。它公开了具有厚里面部分的单块磨轮比带隔离件的直磨轮更硬。但是，美国专利 5,313,742 的磨轮缺点在于该里面部分不用于切割，因此里面部分的大量磨料被浪费了。由于薄磨轮（尤其用于切割氧化铝-碳化钛的磨轮）使用昂贵的磨料（如金刚石），因此由于浪费的磨料量使美国专利 5,313,742 磨轮的成本高于直磨轮。

需要开发一种与常规磨轮相比具有提高刚性的直的单块薄磨轮。除了磨轮几何形状以外，其刚性是由磨轮构造材料的固有硬挺性决定的。单块磨轮基本上由磨粒和粘合剂组成，该粘合剂用于将磨粒固定成所需的形状。以前，在用于切割硬物件（如硅晶片和氧化铝-碳化钛圆盘）的薄磨轮中通常使用金属粘

合剂。用于粘结金刚石磨粒的各种金属粘合剂组合物（如铜、锌、银、镍或铁合金）是本领域已知的。现在发现将至少一种活性金属组分加至金属粘合剂组合物中，可在形成粘结过程中使金刚石磨粒与该活性金属组分发生化学反应，形成整体的增强磨粒复合物。磨粒固有的很高硬挺性和磨粒与金属之间的化学键一起形成明显高硬挺性的研磨结构。

因此，本发明提供一种磨轮，它包括均匀宽度约为 20-2500 微米的直的单块磨粒增强磨盘，它主要由约 2.5-50 体积％磨粒和余量的粘合剂组成，所述粘合剂包括一种金属组分和一种经烧结与磨粒形成化学键的活性金属，所述活性金属的含量实际使制得的磨粒增强磨盘的弹性模量比同样组成但无活性金属的烧结磨盘的弹性模量至少高 10％。

本发明还提供一种工件的切割方法，它包括使工件与磨轮接触的步骤，所述磨轮包括具有约 20-2500 微米范围内的均匀宽度的直的单块磨粒增强磨盘，它主要由约 2.5-50 体积％磨粒和余量的粘合剂组成，所述粘合剂包括一种金属组分和一种经烧结与磨粒形成化学键的活性金属，所述活性金属的含量实际使制得的磨粒增强磨盘的弹性模量比同样组成但无活性金属的烧结磨盘的弹性模量至少高 10％。

本发明还提供一种磨具的制造方法，它包括：

(a)提供预定比例的颗粒组分，包括：

(1)磨粒；

(2)主要由主要量的铜和次要量的锡组成的金属组分；和

(3)一种通过烧结可与磨粒形成化学键的活性金属；

(b)将该颗粒组分混合成均匀的组合物；

(c)将该均匀的组合物置于预定形状的模具中；

(d)向该模具施加约 345-690MPa 的压力，施压的时间足以形成成型制品；

(e)将该成型制品加热至约 500-900℃的温度，加热的时间足以将该金属组分和活性金属烧结成烧结粘合剂，从而将磨粒和烧结粘合剂结合成磨粒增强复合物；和

(f)冷却该磨粒增强复合物，形成磨具。

本发明可用于直的、圆形的单块磨轮。术语“直的”是指由磨轮的芯轴孔半径至磨轮外半径的所有径向范围内其轴向厚度均是均匀的。这些磨轮的一个重要的用途是以精确并且减少切口损耗的方式切割薄片（如晶片和无机物圆

盘）。通过在高切割速度（即与工件接触的磨轮表面速度）操作磨轮通常可获得优良的结果。使用相当小、厚度均匀并且大直径的磨轮通常可达到这种性能标准和操作条件。因此，本发明较好磨轮主要具有高径厚比的特征。径厚比定义为磨轮的外径与轴向横截面尺寸(即磨轮的厚度)之比。径厚比应为约 20-6000:1，较好约 100-1200:1，更好约 250-1200：1。

磨轮的厚度均匀性保持了高精度公差以获得所需的切割性能。较好的是，均匀的厚度约为 20-2500 微米，较好约为 100-500 微米，最好约为 100-200 微米。厚度的偏差较好小于约 5 微米。通常芯轴孔的直径约为 12-90mm，磨轮直径约为 50-120mm。

术语“单块”是指由芯轴孔的半径至磨轮的半径的磨轮材料具有完全均匀的组成。也就是说单块磨轮整体基本上是一种磨粒嵌入烧结粘合剂中的磨盘。该磨盘不具有用于结构支承研磨部分的完整的非研磨部分（如固定磨轮研磨部分的金属芯）。

本发明磨盘基本上包括三种组分，即磨粒、金属组分和活性金属组分。金属组分和活性金属组分构成烧结粘合剂用于将磨粒保持在所需形状的磨轮中。所述烧结粘合剂是将金属组分置于合适的烧结条件下形成的。术语“活性金属”是指在烧结时能与磨粒表面反应的元素或化合物。因此活性金属与磨粒化学键合。另外，活性金属的含量实际将磨粒和烧结粘合剂结合成为磨粒增强复合物。结果，通过适当挑选合适的高刚性和高硬度磨粒，通过使活性金属组分与磨粒在烧结过程中化学键合，可增强磨粒-烧结粘合剂基质的总体硬挺性。

挑选磨粒主要需考虑磨料的硬度要比欲切割的物件的硬度大。薄磨轮的磨粒通常选自很硬的物质，因为这些磨轮通常用于切割极硬的物件，如氧化铝-碳化钛。如上所述，磨料还具有足够高的刚性以增强粘结结构是重要的。挑选磨料的这种附加标准通常还包括确保磨料的弹性模量高于（最好明显高于）烧结粘合剂的弹性模量。适用于本发明的代表性硬磨料是所谓的超级磨料，如金刚石和立方氮化硼，以及其它硬磨料如碳化硅、熔凝氧化铝、微晶氧化铝、氮化硅、碳化硼和碳化钨。还可使用至少两种这些磨料的混合物。较好的是金刚石。

通常采用细颗粒状的磨粒。对于最高直径约为 120mm 的磨轮，磨粒的粒度一般应约为 0.5-100 微米，较好约 10-30 微米。对于更大直径的磨轮，磨粒的

粒度可适当增加。

本发明金属组分可以是单种金属元素或者多种金属元素的混合物。适用于本发明的代表性金属包括铜、锡、钴、铁、镍、银、锌、锑和锰。混合物的例子包括铜-锡、铜-锡-铁-镍、铜-锌-银、铜-镍-锌、铜-镍-锑。还可使用金属化合物如碳化钴-钨和碳化镍-铜-锑-钼，以及含非金属的合金。该非金属组分通常增强金属的硬度或者降低金属的熔融温度，有助于降低烧结温度，避免金刚石置于高温而损坏。这种含非金属的化合物和合金的例子包括镍-铜-锰-硅-铁和镍-硼-硅。使用的金属组分一般是小粒度粉末。多元素金属组分的粉末颗粒可以是各元素颗粒、预合金或两者的混合物。

由于活性金属组分，使烧结的粘合剂与磨粒化学键合而非仅仅夹持磨粒。因此，这种活性粘结的新的薄磨轮的磨粒可以比非活性粘结的磨轮中的磨粒更多地朝工件露出。另外，可使用更软的烧结粘合剂组合物。这些特征的优点在于磨轮可更自由地进行切割，较少有堵塞(load)的倾向，因此可在低能耗下操作。铜-锡是作为金属组分产生相对软粘合的较好的组合物。

对于铜-锡金属组分，一般主要组分(即>50 重量%)为铜，次要组分(即<50 重量%)为锡。较好的是铜-锡组合物主要由约 50-90 重量%铜和约 10-40 重量%锡组成，较好由约 70-90 重量%铜和约 10-30 重量%锡组成，更好由约 70-75 重量%铜和 25-30 重量%锡组成。如下面制备新的活性粘结的薄磨轮时将描述的那样，用于制造磨轮的金属组分通常是细颗粒状的。

选择活性金属组分使之与烧结粘合剂的金属组分和磨粒均相容。也就是说，在烧结条件下，该活性金属应与所述金属组分一起密实成高强度烧结粘合剂，并且它应与磨粒表面反应与之形成化学键。活性金属组分的选择很大程度上取决于所述金属组分的组成、磨粒的组成和烧结条件。作为活性金属组分的代表性材料有钛、锆、铪、铬、钽及至少两种这些材料的混合物。在混合物中，该活性组分的金属可以由各金属颗粒或者合金提供。较好为钛，尤其与铜-锡金属组分和金刚石磨粒一起使用。

可以以元素的形式或者以金属与非活性组分元素的化合物形式加入活性组分。元素钛与水或氧在低温下反应形成二氧化钛，从而在烧结过程中不能与磨料反应。因此当存在水或氧时加入元素钛不是最好。如果以化合物的形式加入钛，该化合物应能在烧结步骤前分解成元素形式，以便钛与磨料反应。适用于本发明的较好的化合物形式的钛是氢化钛 TiH_2，在高达约 500℃它是稳定

的。高于 500℃，氢化钛会分解成钛和氢。

金属组分和活性金属组分较好以颗粒状混合成粘合剂组合物。该颗粒较好具有小的粒度以便烧结的粘合剂具有均匀的浓度，在烧结过程中很好地与磨粒接触，并且与磨粒形成良好的粘结强度。细颗粒的最大粒度较好约 44 微米。可使用特定筛目的筛网进行过筛来测定金属粉末的粒度。例如，标称最大 44 微米的颗粒可通过 325 美国标准目的筛网。

在一个较好的实例中，活性粘结的薄磨轮包括约 45-75 重量％铜、约 20-35 重量％锡和约 5-20 重量％活性金属（总共为 100 重量％）组成的烧结粘结剂。在一个更好的实例中，所述活性金属是钛。如上所述，较好以氢化钛的形式加入钛组分。元素钛与氢化钛的分子量之间的微小偏差通常可忽略。但是，为了清楚起见，除非另有说明，否则本文中所述的组成为钛的百分数。

所述新磨轮基本上是由所谓的“冷压”或“热压”型密实法制得。在冷压法(有时称为无压烧结)中，将组分的混合物装入一个所需形状的模具中，在室温施加高压以获得密实但脆性的成型制品。通常所述高压为高于约 300MPa。随后，释放压力，从模具中取出成型制品，再加热至烧结温度。加热烧结通常是将成型制品置于惰性气体中进行的，其压力低于预烧结步骤的压力(即低于约 100MPa，较好低于约 50MPa)。还可在真空中进行烧结。在这种低压烧结过程中，成型制品（如薄磨轮的圆盘）较好置于模具中和/或夹在两片平板中。

在热压法中，将颗粒粘合剂组合物的组分混合物置于模具(通常为石墨模具)中，如冷压法那样施加高压。但是使用惰性气体并且在升温的同时保持高压，从而在预制件处于压力下的同时进行密实。

磨轮制备方法的第一步包括将组分装入成形模具。加入的组分可以是单独的磨粒、金属组分颗粒和活性金属组分颗粒均匀的混合物。可使用本领域已知的任何合适的机械混合设备将预定比例的磨粒和金属颗粒混合成混合物以制得所述均匀的混合物。说明性的混合设备包括双锥式滚混机、双壁 V 型滚混机、螺带式混合机、水平鼓式滚混机和固定外壳/内螺杆混合机。

铜和锡可预先制成合金并以青铜合金颗粒的形式加入。另一种方式包括将附加的铜和/或锡颗粒、活性金属颗粒和磨粒合并并混合成均匀的青铜合金颗粒组合物坯料。

在本发明的一个基本实例中，在烧结粘合剂以前磨粒是未涂覆的。也就是说，磨粒表面上不存在金属。另一个实例要求在机械混合所有组分以前，用一

层含所有或部分活性金属组分的层预涂覆磨粒。这种技术可在烧结过程中增强磨粒和活性金属之间形成化学键。

所述涂层厚度可以是分子的厚度(例如可由化学气相沉积法或物理气相沉积法制得)或者大分子的厚度。当使用分子的厚度时，推荐在磨粒和粘合剂组合物组分的混合物中增加带有添加活性金属的预涂层中的活性金属量。通常，分子厚度的预涂层不单独拥有足量的活性金属，来达到本发明的有益结果。

用下列方法可获得大分子厚度的涂层：(A)将活性金属组分的细粉末和有效量的短效液体粘合剂混合成均匀的组合物，形成粘性糊浆；(B)将磨粒与该粘合剂糊浆混合在一起，使粘合剂糊浆至少湿润大部分磨粒表面；和(C)干燥液体粘合剂(通常加热)，使残留的活性金属粉末颗粒机械附着在磨粒上。机械附着的目的是至少在烧结(此时的化学键合能使附着永久化)之前能使活性金属颗粒保持与磨粒接近的状态。可使用任何常规的短效液体粘合剂制备糊浆。术语“短效”是指在升温下，较好在低于烧结温度下在对烧结过程无不利影响的情况下该液体粘合剂能够离开粘合剂组合物。该液体粘合剂应具有足够的挥发性，以便在烧结过程中基本完全蒸发和/或热解，不残留会影响粘合剂功能的残余物。较好的是该液体粘合剂能在约 400℃蒸发。该液体粘合剂可通过许多本领域众所周知的方法与金属颗粒掺混在一起。

将装入成形模具的组分混合物包括少量任选的磨料工业常用的加工助剂，如石蜡（Acrowax）和硬脂酸锌。

一旦制得均匀的混合物，就将其装入合适的模具中。在一种较好的冷压烧结方法中，在环境温度下用外加的机械压力至约 345-690MPa 可压缩模具中的物料。在该操作中可例如使用平板压机。压力可保持约 5-15 秒，随后释放压力。随后将模具物料升温至烧结温度，该温度应高得足以导致粘合剂组合物密实，但是不完全熔融。烧结温度至少约 500℃。加热应在惰性气氛中进行，例如在低绝对压力真空下或者在惰性气体层下进行。应选择金属粘合剂和活性金属组分使之无需在会对磨粒产生不利影响的高温下进行烧结，这一点是重要的。例如，在高于约 1100℃的温度下金刚石会石墨化。因此，金刚石磨轮的烧结应设计在低于该温度、较好低于约 950℃，更好低于约 900℃的温度下安全地进行。烧结温度保持的时间应有效地烧结该粘合剂组分并同时使活性金属与磨粒反应。烧结温度通常保持约 30-120 分钟。

在一种较好的热压方法中，加工条件与冷却法基本相似，但是将压力保持

至烧结完成。在无压烧结法或热压法中，烧结后使模具降温至环境温度，并取出烧结制品。用常规方法(如研磨)修整产品以便尺寸偏差符合要求。

上述烧结和粘结将磨粒结合至烧结粘合剂中，形成磨粒增强复合物。为了有助于制造磨粒增强复合物并提供露出良好的磨料，在烧结制品中磨粒的用量较好约为 2.5-50 体积%，余量为烧结粘合剂。

本发明较好的磨具是磨轮，因此，常用的模具形状是薄圆盘状。可使用实心的圆盘模具，在这种情况下烧结后可除去圆盘中心部分，形成芯轴孔。或者，可使用圆环状模具以便原位形成芯轴孔。后一种方法由于避免丢弃烧结圆盘的带有磨料的中央部分，而避免了浪费。

通过成功地形成磨粒增强复合结构，磨粒可有助于磨轮的硬挺性。因此，如上所述，选择磨粒不仅为了传统的硬度、抗冲击等特性，而且还为了例如用弹性模量确定的硬挺性，这一点是重要的。尽管不愿受具体理论的束缚，但是相信通过活性金属组分的化学键合结合在烧结粘合剂中的很刚性的磨粒对复合物的硬挺性具有很大的贡献。认为这种贡献的原因是操作过程中负载在复合物上的应力被有效地转移至固有高硬挺性的磨粒上的缘故。因此可以通过实施本发明得到硬挺性高于相同厚度的常规磨轮的直的活性粘结的薄磨轮。这种新磨轮用于提供更精确的切割并且切屑较少，与传统的直磨轮相比无进一步切口损耗。

与常规磨轮相比该新磨轮的硬挺性有明显的增强。在一个较好的实例中，活性粘结磨轮的弹性模量高于单独烧结粘合剂组分(即金属组分加上活性金属组分，不含磨粒)的弹性模量，它至少约 100GPa，较好至少约 150GPa。在另一个较好的实例中，磨轮的弹性模量是无磨粒的烧结粘合剂弹性模量的至少约两倍。

下面用一些代表性实例的实施例说明本发明。除非另有说明，否则其中所有的份、比例和百分数均按重量计的，粒度以美国标准筛网目尺寸单位表示。所有原始得到的重量和测量单位中非 SI 单位已经换算成 SI 单位。

实施例 1

以 59.63%Cu、23.85%Sn 和 16.50%TiH_2的比例将铜粉(<400 目)、锡粉(<325 目)和氢化钛(<325 目)合并在一起。使这种粘合剂组合物通过 165 目的不锈钢筛网以除去团聚物，在 Turbula 牌混合机(Glen Mills, Inc., Clifton, New Jersey)中将过筛的混合物彻底混合30分钟。向该金属混合物中加入购自GE Superabrasives, Worthington, Ohio的金刚石磨粒(15-25微米)，形成含18.75体积%金刚石的混合物。将这种混合物在Turbula混合机中掺混1小时，得到均匀的磨料和粘合剂的组合物。

将该磨料和粘合剂的组合物置于一个模具中，该模具内腔外径为121.67mm，内径6.35mm，均匀的深度为0.81mm。在环境温度下在414MPa(4.65吨/cm^2)的压力下将模具压制10秒钟得到磨轮坯料。从模具中取出磨轮坯料，置于两块水平的平板之间(上板加660g负荷)，在真空中加热至850℃ 2小时。使热烧结的产品逐渐冷却至250℃，随后快速冷却至环境温度。在表1所示的条件下用常规方法(包括修整预定的次数)将磨轮研磨至最终尺寸并初次打磨。

表 1

实施例1-2的修整条件

被修整磨轮	
速度	5593转/min
进料速度	100mm/min
从边缘露出	3.68mm
修整磨轮	37C220-H9B4型
组成	碳化硅
直径	112.65mm
速度	3000转/min
横向速度	305mm/min
走次数	
2.5微米	40次
1.25微米	40次
初始打磨	
磨轮速度	2500转/min
打磨棒	37C500-GV型
打磨棒宽度	12.7mm
进入	2.54mm
进料速度	100mm/min
打磨次数	12.00次

实施例 2 和比较例 1

使用如实施例 1 所述制得的新磨轮和同样尺寸的常规市售磨轮(比较例 1)从粘附在石墨基材上的 3M-310 型氧化铝-碳化钛块(长 150mm×宽 150mm×1.98mm 厚，购自美国 3M 公司)上切割多片薄片。比较例 1 的磨轮是由 18.9 体积% 15/25 微米金刚石磨粒在含 53.1 重量%钴、23.0 重量%镍、12.7 重量%银、5.4 重量%铁、3.4 重量%铜和 2.4 重量%锌的粘合剂中组成的。每次切片前，如表 1 所述对磨轮打磨，但是打磨一次并且使用 19mm 宽的打磨棒(比较例 1 为 12.7mm)。在每次试验中，磨轮固定在两个外径为 106.93mm 的金属支承间隔件之间。磨轮速度为 7500 转/min(比较例 1 为 9000 转/min)，进料速度为 100mm/min，切割深度为 2.34mm。切割用 56.4 升/min 流量的 5%防锈剂稳定的去离子水冷却，该冷却水是由一个 1.58mm×85.7mm 的矩形喷嘴以 275kPa 的压力喷出的。

切割结果列于表 2。对所有切割性能标准新磨轮均具有良好性能。比较例 1 的磨轮需要在比新磨轮高 20%的转速，多消耗约 45%功率(约 520W 对 369W)的情况下运行。

表 2

切片数	累计切片数	累计切割长度 (m)	磨轮损耗			工件		切割直线性 (微米)	切割旋转功率 (W)
			半径 (微米)	累计 (微米)	因子[1] (微米/米)	最大切屑 (微米)	平均切屑 (微米)		
实施例 1									
9.00	9.00	1.35	5.08	5.08	3.70	8.00	<5	<5	
9.00	18.00	2.70	0.00	5.08	0.00	9.00	5.00	<5	
9.00	27.00	4.05	0.00	5.08	0.00	11.00	<5	<5	368-296
9.00	36.00	5.40	10.16	15.24	7.40	6.00	<5	<5	
9.00	45.00	6.75	2.54	17.78	1.90	10.00	5.00	<5	
9.00	54.00	8.10	2.54	20.32	1.90	11.00	5.00	<5	312-368
9.00	63.00	9.45	10.16	30.48	7.40	8.00	<5	<5	
9.00	72.00	10.8	2.54	33.02	1.90	9.00	<5	<5	
9.00	81.00	12.0	2.54	35.56	<0.5	9.00	<5	<5	376-328
比较例 1									
9.00	9.00	1.35	5.08	5.08	3.70	11.00	<5	<5	520-536
9.00	18.00	2.70	10.16	15.24	7.40				
9.00	27.00	4.05	5.08	20.32	3.70				
9.00	36.00	5.40	2.54	22.86	1.90	10.00	<5	<5	
9.00	45.00	6.75	5.08	27.94	3.70				
9.00	54.00	8.10	2.54	30.48	1.90				
9.00	63.00	9.45	5.08	35.56	3.70	14.00	<5	<5	560-576

[1] 磨损因子＝磨轮磨损半径除于切割的工件长度

实施例 3 和 4 以及比较例 2-8

试验磨粒增强磨轮组合物的硬挺性。以表 3 所示的比例将各种带有或不带有金刚石磨粒的细金属粉末合并在一起，如实施例 1 所述将其混合至组分均匀。在狗骨形模具中在环境温度下将该组合物在约 414-620MPa(30-45 吨/cm^2)的压力下压制约 5-10 秒，随后如实施例 1 所述在真空下进行烧结制得拉伸试验的试样。

在 Instron 拉伸试验机中对试样进行声波和标准拉伸模量测定。结果列于表 3。磨粒增强试样(实施例 3 和 4)的弹性模量超过 150GPa。实施例 4 提高金刚石的浓度明显提高拉伸模量，证实金刚石与组合物形成一体。相反，比较例 2 表明由于无金刚石相同粘合剂组合物不具有磨粒增强效应，硬挺性明显下降。同样，比较例 3 表明金刚石嵌入无活性组分的青铜合金粘合剂组合物中，具有较差的硬挺性。

在比较例 4，使用以前购自 General Electric Co. 的金刚石磨粒，制造者说明该磨粒表面涂覆有约 1-2 微米厚的钛。与不存在活性组分的试样(比较例 3)相比硬挺性仅稍有改进，但是与实施例组合物相差很多。估计效力较低的原因在于存在的活性组分太少，在于烧结前表面上的钛是碳化物形态，使钛与其它金属组分相容较差，和/或在于磨粒上非碳化钛发生氧化。

比较例 5 和 7 表明，铜/锡/镍/铁粘合剂组成不同的常规薄磨轮的弹性模量仅约 100GPa。比较例 6 和 8 的磨轮组成与比较例 5 和 7 相同，但是没有金刚石磨粒。这些比较例表明带有或不带有金刚石磨粒的粘合剂组合物的硬挺性大致相同。这证实无活性金属组分的粘合剂未将金刚石结合至粘合剂中以增强结构。

表 3

	实施例 3	实施例 4	比较例 2	比较例 3	比较例 4	比较例 5	比较例 6	比较例 7	比较例 8
铜(重量%)	59.50	59.50	59.50	80.00	80.00	70.00	70.00	62.00	62.00
锡（重量%）	24.00	24.00	24.00	20.00	20.00	9.10	9.10	9.20	9.20
钛（重量%）	16.50	16.50	16.50						
镍（重量%）						7.50	7.50	15.30	15.30
铁（重量%）						13.40	13.40	13.50	13.50
金刚石（体积%）	18.80	30.00		18.80	18.8*	18.80		18.80	
声波模量（GPa）	176.00	220.00		67.00	80.00	95.00		99.00	
拉伸模量(GPa)	276.00		110.00	60.00	84.00		106.00	103.00	95.00

* 涂覆约 1-2 微米钛的金刚石

尽管实施例中选择本发明的具体形式进行了说明，但是上面以具体条件进行的描述仅出于对本发明这些形式进行说明的目的，这些描述对权利要求书限定的本发明范围不构成任何限制。