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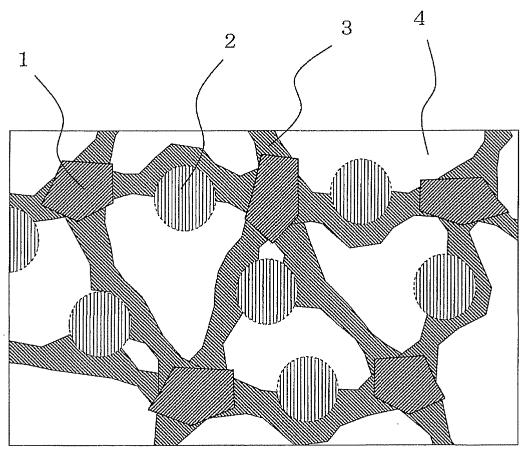
(54) VITRIFIED GRINDING WHEEL AND METHOD OF MANUFACTURING THE SAME

(57) A vitrified grinding wheel having a porosity (preferably 30 to 70 volume percent), a degree of concentration of abrasive grains (preferably 50 to 160) and an abrasive grain diameter (preferably 10 to 90 μm) based on the preset processing efficiency and processing precision of grinding, preferably based on a processing precision ranging from 0.1 to 1.6 Rz (μm) and a processing efficiency ranging from 0.1 to 2.0 mm^3/(mm • sec), and a method of manufacturing the same.

Fig. 1



EP 1 634 678 A1

Description

Field of the Invention

[0001] The present invention relates to a vitrified grinding wheel in which abrasive grains are bonded with a vitrified binder, and a method of manufacturing the same. More particularly, the present invention relates to a vitrified grinding wheel yielding good processing precision and grinding precision when grinding small-diameter inner surfaces of ground products, and to a method of manufacturing the same.

Technical Background

[0002] Since the degree of binding and composition of vitrified grinding wheels are readily adjusted and they afford resistance to water, alkali, and oil, they are widely employed in grinding and polishing operations, including precision grinding.

[0003] For example, in small-diameter internal grinding, in which the inner surfaces of small-diameter nozzles such as engine injection nozzles are ground, the peripheral speed of the grinding wheel is limited and the quill rigidity becomes low. Thus, in order to maintain good grinding, it is required to make the diameter of the grinding wheel as large as possible. For such reasons, grinding wheels having diameters close to those of the inner diameter of the object being processed are employed in small-diameter internal grinding. However, in such grinding, the chip length increases and clogging tends to occur. These tendencies are particularly marked when the grinding efficiency is increased.

[0004] Fig. 2 shows the relation between the effective cutting edge spacing of the grinding wheel and the chip pocket in internal grinding. As shown in Fig. 2, to prevent clogging and increase processing efficiency during grinding, the method (Fig. 2 (B)) of increasing the abrasive grain diameter and increasing the size of the effective cutting edge spacing *We* and chip pocket *P* relative to the norm (Fig. 2(A)) is conceivable. However, in this method, since the effective cutting edge spacing We is broadened, the processing precision (surface roughness) ends up decreasing. On the other hand, to increase processing precision, the method of reducing the abrasive grain diameter and decreasing the size of the effective cutting edge spacing *We* and chip pocket *P* relative to the norm (Fig. 2(A)) is also conceivable (Fig. 2(C)). However, in this method, since the volume of chip pocket *P* is reduced, the chip pocket ends up quickly filling with chips of the ground products. When grinding is further continued in this state, the grinding wheel clogs, causing fusion. Due to this tradeoff between the improvement of the processing efficiency and that of processing precision of grinding, it has been difficult to simultaneously achieve both.

[0005] Conventionally, attempts have been made to simultaneously achieve processing efficiency and processing precision of grinding. For example, the method of decreasing the degree of concentration of abrasive grains given by the ratio of abrasive grains present in the grinding wheel to increase processing efficiency and processing precision of grinding has been conceived. However, when the degree of concentration of abrasive grains is reduced, the binding property between abrasive grains decreases, causing a problem in the binding of abrasive grains. Further, the dispersion of abrasive grains decreases, causing a problem that abrasive grains cannot be uniformly dispersed in the grinding wheel. Thus, in methods of reducing the degree of concentration of the abrasive grains, it has been difficult to achieve both processing efficiency and processing precision of grinding.

[0006] The method of replacing a portion of the cBN abrasive grains with a hollow inorganic substance is also known (see Japanese Unexamined Patent Publication (KOKAI) Showa No. 62-251077). In this method, a hollow inorganic substance is pulverized during grinding to form pores, which would be expected to produce an effect similar to that of chip pockets. However, in grinding wheels in which a portion of the cBN abrasive grains is replaced with a hollow inorganic substance and the degree of concentration is made about 100, dispersion of the abrasive grains deteriorates due to the decreased degree of concentration, making it difficult to obtain grinding wheels in which the abrasive grains are uniformly dispersed. Further, since the hollow inorganic substance is also held by a vitrified binder, the vitrified binder that originally should have held the cBN abrasive grains ends up being trapped in the hollow inorganic substance. Thus, when employing a hollow inorganic substance, it becomes necessary to use more vitrified binder than usual, resulting in a drawback in the form of decreased porosity. Further, when the hollow inorganic substance is damaged during grinding, the vitrified binder used to bind the hollow inorganic substance ends up remaining in the grinding wheel, resulting in a drawback in the form of impaired grinding.

[0007] Methods of forming pores by employing organic pore-forming materials such as walnuts, wood chips and the like are known. The pore-forming materials are incorporated into a molded product prior to calcination and burned out during calcination, yielding pores in the grinding wheel obtained after calcination. The use of such a pore-forming material is desirable in that it does not have the drawbacks encountered when fillers such as a hollow inorganic material are incorporated into the grinding wheel and permits the achievement of a low degree of concentration.

[0008] However, depending on the type of pore-forming material employed, there is a drawback in that shrinking tends to occur to a greater degree than in common grinding wheels in which common alumina-based (A-based) abrasive grains employing WA abrasive grains (white alumina abrasive grains) and the like are used because the abrasive grains are not oxides and a large quantity of vitrified binder is employed. There are further drawbacks in that the use of conventional pore-forming materials makes it hard to uniformly disperse the pores and is unsuited to vitrified cBN grinding wheels in which more uniform distribution of abrasive grains is required than in common grinding wheels.

[0009] In recent years, for the purpose of improving conventional pore-forming materials, methods of reducing shrinkage due to calcination and uniformly dispersing pores even when manufacturing vitrified grinding wheels in which the degree of concentration of abrasive grains is made less than 200 have been known (for example, Japanese Unexamined Patent Publication (KOKAI) No. 2000-317844). The grinding wheels obtained by such methods afford advantages in that, even when the degree of concentration is small, less than 200, the grinding ratio is high, grinding burns and fusion tend not to occur, and it is easy to use.

[0010] However, even in the aforementioned method, when the degree of concentration is further lowered, that is, when pore-forming materials having a diameter greater than the average grain diameter of the abrasive grains are employed, the spacing between individual abrasive grains widens and thus the effective cutting edge spacing increases. As a result, there is a problem in that good processing precision cannot be maintained. The above-cited method also presents the problem of inadequate uniformity of pores and abrasive grains in the grinding wheel. Accordingly, there is a need for further improvement in the above-cited method for maintaining good processing efficiency and processing precision even in grinding wheels in which the degree of concentration has been further reduced.

[0011] Thus, the present invention was devised to solve the above-described problems of prior art, and it is an object of the present invention to provide a vitrified grinding wheel in which a prescribed porosity is maintained and the pores and abrasive grains are uniformly disposed even when small-diameter abrasive grains are employed.

[0012] An another object of the present invention is to provide a method of manufacturing vitrified grinding wheels capable of maintaining a prescribed porosity in the grinding wheel and achieving uniform dispersion of abrasive grains and pores in the grinding wheel even when small-diameter abrasive grains are employed.

Disclosure of the Invention

[0013] The present inventors conducted extensive research into the relation between the effective cutting edge spacing of abrasive grains and chip pocket volume for the purpose of achieving both processing efficiency and processing precision of grinding to solve the above-stated problems. As a result, they discovered that presetting the processing efficiency and processing precision of grinding and then setting the porosity, degree of concentration of abrasive grains, and abrasive grain diameter based on the preset processing efficiency and processing precision of grinding resulted in a method permitting improvement in both grinding efficiency and processing surface roughness; the present invention has been devised on this basis.

[0014] That is, the object of the present invention is achieved by the following vitrified grinding wheel;

(1) A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, characterized by having a porosity, a degree of concentration of abrasive grains and an abrasive grain diameter based on the preset processing efficiency and processing precision of grinding.

(2) The vitrified grinding wheel according to (1), wherein, when said processing precision of grinding ranges from 0.1 to 1.6 Rz (μm), the processing efficiency of grinding ranges from 0.1 to 2.0 mm^3/(mm • sec).

(3) The vitrified grinding wheel according to (1) or (2), wherein said porosity ranges from 30 to 70 volume percent with respect to the volume of the whole grinding wheel.

(4) The vitrified grinding wheel according to any of (1) to (3), wherein said porosity comprises a forced porosity based on burnout pores formed by burning out a pore-forming material.

(5) The vitrified grinding wheel according to (4), wherein said forced porosity ranges from 5 to 35 volume percent with respect to the volume of the whole grinding wheel.

(6) The vitrified grinding wheel according to (4) or (5), wherein said pore-forming material has a size 0.1 to 3 times the average grain diameter of the abrasive grain.

(7) The vitrified grinding wheel according to any of (1) to (6), wherein the ratio of pores having a size 1 to 3 times the average grain diameter of the abrasive grain in the volume of whole pores ranges from 20 to 70 volume percent.

(8) The vitrified grinding wheel according to any of (1) to (6), wherein the ratio of pores having a size 0.1 to 1 time the average grain diameter of the abrasive grain in the volume of whole pores ranges from 30 to 70 volume percent.

(9) The vitrified grinding wheel according to any of (4) to (8), wherein said pore-forming material is a polymer compound.

(10) The vitrified grinding wheel according to any of (1) to (9), wherein said abrasive grain has an average grain diameter ranging from 10 to 90 μm.

(11) The vitrified grinding wheel according to any of (1) to (10), wherein said degree of concentration of abrasive grains ranges from 50 to 160.

(12) The vitrified grinding wheel according to any of (1) to (11), wherein said abrasive grain is a cubic boron nitride abrasive grain.

(13) A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, wherein the ratio of pores having a size 1 to 3 times the average grain diameter of the abrasive grain in the volume of whole pores ranges from 20 to 70 volume percent.

(14) A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, wherein the ratio of pores having a size 0.1 to 1 time the average grain diameter of the abrasive grain in the volume of whole pores ranges from 30 to 70 volume percent.

(15) The vitrified grinding wheel according to (13) or (14), wherein said abrasive grain has an average grain diameter ranging from 10 to 90 μm.

(16) The vitrified grinding wheel according to any of (13) to (15), wherein the degree of concentration of said abrasive grains ranges from 50 to 1.60.

The another object of the present invention is achieved by the following method of manufacturing a vitrified grinding wheel;

(17) A method of manufacturing a vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, comprising steps of;

setting a processing efficiency and a processing precision of grinding, and

setting a porosity, a degree of concentration of abrasive grains and an abrasive grain diameter based on the processing efficiency and processing precision.

(18) The method of manufacturing according to (17), wherein said processing precision of grinding is set within a range of 0.1 to 1.6 Rz (μm) and said processing efficiency of grinding is set within a range of 0.1 to 2.0 $mm^3/(mm \bullet sec)$.

(19) The method of manufacturing according to (17) or (18), wherein said porosity is set within a range of 30 to 70 volume percent with respect to the volume of the whole grinding wheel.

(20) The method of manufacturing according to any of (17) to (19), wherein said porosity comprises a forced porosity based on burnout pores formed by burning out a pore-forming material.

(21) The method of manufacturing according to (20), wherein said forced porosity is set within a range of 5 to 35 volume percent with respect to the volume of the whole grinding wheel.

(22) The method of manufacturing according to (20) or (21), wherein a pore-forming material having a size 0.1 to 3 times the average grain diameter of the abrasive grain is employed as said pore-forming material.

(23) The method of manufacturing according to any of (17) to (22), wherein a polymer compound is employed as said pore-forming material.

(24) The method of manufacturing according to any of (17) to (23), wherein an abrasive grain having an average grain diameter ranging from 10 to 90 μm is employed as said abrasive grain.

(25) The method of manufacturing according to any of (17) to (24), wherein said degree of concentration of abrasive grains is set within a range of 50 to 160.

(26) The method of manufacturing according to any of (17) to (25), wherein a cubic boron nitride abrasive grain is employed as said abrasive grain.

[0015] In the present invention, the processing efficiency and processing precision of grinding are preset. Thus, the present invention can provide both a vitrified grinding wheel having a porosity, degree of concentration of abrasive grains, and abrasive grain diameter based on the aforementioned processing efficiency and processing precision of grinding, and a method of manufacturing the same. For example, the present invention can provide a grinding wheel having good processing precision of less than or equal to 1.0 Rz (μm) even at a processing efficiency of grinding of greater than or equal to 0.3 $mm^3/(mm \bullet sec)$. Further, the present invention can provide a grinding wheel in which abrasive grains and pores are uniformly dispersed and the degree of concentration is maintained at 50 to 160 with a porosity of 30 to 70 volume percent by containing a forced porosity of 5 to 35 volume percent based on burnout pores even when small-diameter abrasive grains having an average grain diameter of 10 to 90 μm are employed. As a result, the present invention affords a uniform cutting edge spacing comparable to that of large-diameter abrasive grains even when employing small-diameter abrasive grains, and maintains the chip pocket volume. Thus, it provides both a vitrified grinding wheel in which clogging tends not to occur during grinding, fusion is prevented, and both grinding processing efficiency and grinding processing precision are achieved, and a method of manufacturing the same.

Brief Description of Drawings

[0016]

Fig. 1 is an enlarged schematic cross-sectional view of the vitrified grinding wheel of the present invention.

Fig. 2 is a drawing showing the relation between the effective cutting edge spacing *We* and the chip pocket *P* in a grinding wheel during internal grinding.

Fig. 3 is an enlarged schematic cross-sectional view showing the structure of a grinding wheel manufactured using a conventional burnout material.

Fig. 4 is an enlarged schematic explanatory drawing showing the structure of a grinding wheel manufactured without using a burnout material.

Fig. 5 is an explanatory drawing showing the relation between the grinding efficiency ratio and the effective cutting edge spacing in the grinding wheel of the present invention and a conventional grinding wheel.

Fig. 6 is an explanatory drawing descriptive of the arrangement of abrasive grains and the effective cutting edge spacing in the present invention.

Fig. 7 is a drawing showing the grinding efficiency ratio when the effective cutting edge spacing is 0.1 mm in a preferred embodiment of the present invention and a comparative example.

Fig. 8 (1) to (3) shows the results (power consumption, surface roughness, and abrasion) when internal grinding was conducted at a grinding processing efficiency of 0.3 $mm^3/(mm \cdot sec)$ with the grinding wheels of Examples 1 to 3 and Comparative Example 2.

Fig. 9 (1) to (3) shows the results (power consumption, surface roughness, and abrasion) when internal grinding was conducted at a grinding processing efficiency of 0.7 $mm^3/(mm \cdot sec)$ with the grinding wheels of Examples 1 and 2.

Best Mode for carrying out the Invention

[0017] The vitrified grinding wheel of the present invention and manufacturing method thereof will be described in greater detail below.

[Vitrified grinding wheel]

<Processing Efficiency and Processing Precision of Grinding>

[0018] The grinding wheel of the present invention has a porosity, a degree of concentration of abrasive grains, and an abrasive grain diameter based on the preset processing efficiency and processing precision of grinding. The processing efficiency of grinding is given as the amount of grinding per second for a grinding wheel width of 1 mm and is normally denoted in units of $mm^3/(mm \cdot sec)$. The processing precision of grinding can be denoted as a surface roughness and is normally denoted as a ten-point average roughness Rz (μm).

[0019] For example, in internal grinding, when attempting to achieve a processing precision of grinding of less than or equal to 1 Rz (μm), the conventional limit of processing efficiency of grinding is about 0.3 $mm^3/(mm \cdot sec)$. By contrast, in the grinding wheel of the present invention, it is possible to achieve a processing efficiency of grinding of greater than or equal to 0.3 $mm^3/(mm \cdot sec)$ even at a grinding precision of less than or equal to 1 Rz (μm). More specifically, even when the processing precision of grinding is set to 0.1 to 1.6 Rz (μm), preferably 0.2 to 1.0 Rz (μm), and more preferably 0.3 to 0.5 Rz (μm), the processing efficiency of grinding can be set to 0.1 to 2.0 $mm^3/(mm \cdot sec)$, preferably 0.2 to 1.0 $mm^3/(mm \cdot sec)$, and more preferably 0.3 to 0.7 $mm^3/(mm \cdot sec)$.

[0020] Here, the relation between the grinding efficiency ratio and the effective cutting edge spacing, We, is shown in Fig. 5 to describe the relation between the above-mentioned processing efficiency of grinding and the effective cutting edge spacing, We. As shown in Fig. 5, for example, when a conventional grinding wheel has an effective cutting edge spacing of 0.1 mm, the grinding efficiency ratio is less than 2. By contrast, when the grinding wheel of the present invention has an effective cutting edge spacing of 0.1 mm, it is possible to make the grinding efficiency ratio greater than or equal to 2 (preferably greater than or equal to 2.5, and more preferably greater than or equal to 3.0). (Fig. 5 shows an example where the grinding efficiency ratio is greater than or equal to 3 when the effective cutting edge spacing is 0.1 mm.) In the grinding wheel of the present invention, abrasive grains of prescribed size (preferably 10 to 90 μm) are selected, and the abrasive grains are not positioned next to one another in the manner of a conventional grinding wheel (see Fig. 2), but are arranged uniformly as shown in Fig. 6, maintaining a certain effective cutting edge spacing. Thus, the grinding wheel of the present invention achieves good processing efficiency (grinding efficiency ratio) while maintaining a prescribed processing precision of grinding.

<Porosity>

[0021] In the present Specification, the term "porosity" means the ratio of the volume of pores (space) without abrasive grains, binder, and other fillers and the like, to the volume of the whole grinding wheel. In the present invention, the porosity is comprised of a forced porosity and a natural porosity. Here, the term "forced porosity" means the ratio of the volume of burnout pores --- formed by burning out a pore-forming material when a molded product containing at least an abrasive grain, a vitrified binder, and a pore-forming material is calcined in a calcination step - to the volume of whole pores. The term "natural porosity" refers to the porosity calculated by subtracting the above forced porosity from the total porosity, and is the ratio occupied in the molded product of gap portions in the abrasive grain, vitrified binder, and pore-forming material prior to calcination.

[0022] In the vitrified grinding wheel of the present invention, the porosity suitably falls within a range of 30 to 70 volume percent, preferably 40 to 60 volume percent, and more preferably 45 to 55 volume percent, of the volume of the whole grinding wheel. When the porosity is greater than or equal to 30 volume percent, fusion is not caused due to inadequate volume of chip pockets and clogging during grinding. Since the pore-forming material is burned out during the calcination in the present invention, better porosity can be ensured than in grinding wheels in which a pore-forming material is not employed; porosities of up to 70 volume percent can be obtained.

[0023] Within this porosity, the forced porosity suitably falls within a range of 5 to 35 volume percent, preferably 20 to 35 volume percent, and more preferably 25 to 35 volume percent, of the volume of the whole grinding wheel. In the vitrified grinding wheel of the present invention, the forced pores formed by the pore-forming material primarily contribute to the improvement of the processing efficiency of grinding. When the forced porosity is greater than or equal to 5 volume percent, grinding can be carried out well. When the forced porosity is less than or equal to 35 volume percent, grinding wheels can be manufactured stably.

[0024] In the vitrified grinding wheel of the present invention, the size of the forced pores formed by burning out the pore-forming material greatly affects grinding wheel performance. For example, the smaller the forced pores, the greater the dispersion of abrasive grains and pores in the grinding wheel. Since increasing dispersion of the abrasive grains and the pores stabilizes the cutting edge spacing, the chip discharge performance increases and power consumption during grinding decreases, which are advantageous with regard to production efficiency. Further, since the strength of the grinding wheel increases, abrasion of the grinding wheel due to grinding decreases, resulting in good durability. The vitrified grinding wheel of the present invention can be one comprising pores (including both forced pores and natural pores) having a size 1 to 3 times the average grain diameter of the abrasive grains in a ratio of 20 to 70 volume percent, preferably 30 to 60 volume percent, and more preferably 30 to 50 volume percent, with respect to the volume of whole pores. The vitrified grinding wheel of the present invention can be one comprising pores having a size 0.1 to 1 time the average grain diameter of the abrasive grains in a ratio of 30 to 70 volume percent, preferably 40 to 70 volume percent, and more preferably 50 to 70 volume percent, with respect to the volume of whole pores. The ratio of pores having a desired size can be adjusted by suitably setting the size and quantity added of the pore-forming material employed. The ratio of pores having a desired size can be calculated by slicing the grinding wheel, measuring the cross-section with a microscope capable of three-dimensional measurement to obtain three-dimensional data, and then analyzing the cross-sectional shape.

<Pore-Forming Material>

[0025] The pore-forming material employed in the present invention is not specifically limited, other than that it be a material that can be burned out in calcination. It is preferable to use a pore-forming material having a burnout starting temperature greater than or equal to the transition temperature of the vitrified binder described further below, and having a burnout ending temperature lower than the maximum temperature within the calcination temperature range of the vitrified binder.

[0026] For example, it is suitable to use a pore-forming material having a burnout starting temperature at least 5°C (more preferably at least 10°C, and further preferably at least 20°C) greater than the transition temperature of the vitrified binder, and having a burnout ending temperature at least 5°C (more preferably at least 10°C, and further preferably at least 20°C) lower than the maximum temperature within the calcinations temperature range of the grinding wheel starting materials including the vitrified binder.

[0027] The pore-forming material desirably has a strength so as to preclude pulverization during stirring of the manufacturing starting materials in the process of manufacturing the grinding wheel. Any pore-forming material having a strength so as to preclude pulverization during stirring may be employed, whether it be solid or hollow.

[0028] The specific gravity of the pore-forming material is desirably greater than or equal to 1 (for example, 1 to 2.5, preferably 1 to 1.5). When the specific gravity of the pore-forming material is greater than or equal to 1, it does not float on the starting materials during stirring and can be uniformly dispersed in the starting materials.

[0029] The size of the pore-forming material is preferably selected according to the size of the desired forced pores. As set forth above, the smaller the forced pores, the lower the power consumption during grinding and the greater the advantage afforded in the form of production efficiency. Further, the smaller the forced pores, the greater the strength of the grinding wheel and the less the abrasion of the grinding wheel during grinding, resulting in good durability. However, when the forced pore diameter becomes excessively small, the processing efficiency during grinding drops. From the above perspectives, the size of the pore-forming material is suitable from 0.1 to 3 times the average grain diameter of the abrasive grains. In particular, from the perspective of power consumption during grinding and grinding wheel durability, the size of the pore-forming material is preferably from 0.16 to 1 time the average grain diameter of the abrasive grains.

For example, when employing cBN abrasive grains as an abrasive grain, when the average grain diameter of the abrasive grains is 22 to 36 μm, a pore-forming material about 3.5 to 36 μm in size can be employed.

[0030] The shape of the pore-forming material is not specifically limited. However, an abrasive grain having a true spherical shape that can be dispersed well during the manufacturing process is preferred.

[0031] The content, as volume percentage, of the pore-forming material in the starting materials is preferably 10 to 50 percent, more preferably 15 to 45 percent, and further preferably 15 to 40 percent. When the volume percentage is greater than or equal to 10 percent, an effect by the formation of burnout pores can be achieved. When the volume percentage is less than or equal to 50 percent, a grinding wheel of suitable strength and durability can be manufactured.

[0032] Specific examples of pore-forming materials are: polymer compounds such as polymethyl acrylate and polymethyl methacrylate, and carbonaceous compounds containing 90 mass percent or more of carbon. The use of polymethyl methacrylate as a pore-forming material is preferred.

<Abrasive Grains>

[0033] The grain diameter of the abrasive grain employed in the present invention can be suitably determined in view of the relation between the porosity and the degree of concentration based on the above-described processing efficiency and processing precision of grinding. For example, within the above-stated ranges of grinding efficiency and processing precision of grinding, it is suitable to use abrasive grains having an average grain diameter ranging from 10 to 90 μm, preferably 18 to 60 μ m, more preferably 20 to 55 μm, and most preferably 25 to 45 μm. With abrasive grains having an average grain diameter of greater than or equal to 10 μm, there is no problem with adhesion between abrasive grains and processing efficiency of grinding does not drop sharply. With abrasive grains having an average grain diameter of less than or equal to 90 μm, a prescribed cutting edge spacing can be maintained and processing precision can be improved.

[0034] The type of abrasive grain is not specifically limited other than that the average grain diameter falls within the above-stated range. For example, cBN abrasive grains, A-based (alumina-based), and C-based (silicon carbide-based) abrasive grains can be employed. When grinding the inner surface of a high-precision component, cBN abrasive grains are preferably employed. One type of abrasive grain may be employed alone, or two or more types may be mixed for use.

[0035] When employing cBN abrasive grains as an abrasive grain, one or more types of common abrasive grains and hollow inorganic materials may be employed as a filler as needed. However, in that case, the quantity of filler employed is suitably adjusted so that the degree of concentration of the cBN abrasive grains ranges from 50 to 160.

[0036] Further, when employing diamond abrasive grains as an abrasive grain, it is desirable to suitably set the types of vitrified binder and pore-forming material and manufacturing conditions such as the calcination temperature to prevent deterioration of the diamond abrasive grains.

[0037] The degree of concentration of the abrasive grains is suitably from 50 to 160, preferably from 75 to 150, and more preferably from 100 to 125. Here, the term "degree of concentration" means the ratio of abrasive grains in the grinding wheel. For example, in the case of diamond abrasive grains, 4.4 ct/cm^3 is the degree of concentration of 100 corresponding to 25 volume percent. Accordingly, the degree of concentration of 200 corresponds to 50 volume percent. When abrasive grains having a different density from diamond abrasive grains are employed, the difference in density from diamond abrasive grains is taken into account and the degree of concentration is established in accordance with the above. When the abrasive grains are cBN abrasive grains, in the same manner as diamond abrasive grains, the degree of concentration of 100 corresponds to about 25 volume percent and the degree of concentration of 200 to about 50 volume percent.

[0038] In the present invention, the degree of concentration is adjusted within a relatively low range of 50 to 160 as well as the porosity is adjusted within a range of 30 to 70 volume percent, as mentioned above, to maintain or increase a prescribed chip pocket volume and prevent clogging and fusion of the grinding wheel during high-efficiency grinding.

<Vitrified Binder>

[0039] In the present invention, the vitrified binder can be suitably selected based on the type of abrasive grain. For example, when manufacturing a vitrified cBN grinding wheel employing cBN abrasive grains as an abrasive grain, the vitrified binder can be, for example, borosilicate glass or crystallized glass. An example of crystallized glass is one from which willemite has been precipitated. To achieve adequate holding strength, the coefficient of thermal expansion of the vitrified binder desirably falls within a range of $\pm$ 2 x 10^{-6} (1/K) (room temperature to 500°C) with respect to the coefficient of thermal expansion of the abrasive grains.

[0040] When employing a vitrified binder for superabrasive grains as a vitrified binder, the temperature for calcining grinding wheel starting materials containing binder is selected based on the type of the vitrified binder for superabrasive grains employed. Since the transition temperature of the vitrified binder for superabrasive grains is lower than the transition temperature of vitrified binders for common abrasive grains, the temperature of calcining grinding wheel starting materials containing vitrified binder for superabrasive grains preferably falls within a range of 650 to 1,000°C, more preferably within a range of 700 to 950°C. At greater than or equal to 650°C, a grinding wheel having a certain strength even after calcination is obtained. At less than or equal to 1,000°C, the superabrasive grains do not deteriorate.

[0041] An example of a preferred composition of the vitrified binder for superabrasive grains is SiO_2: 40 to 70 mass percent, Al_2O_3: 10 to 20 mass percent, B_2O_3: 10 to 20 mass percent, M^1O: 2 to 10 mass percent, and $M^2{}_2O$: 2 to 10 weight percent. Here, M^1 denotes one or more metals selected from alkaline earth metals, and M^2 denotes one or more metals selected from alkali metals.

[0042] The content of vitrified binder can be suitably selected. For example, the content thereof may fall within a range of 13 to 35 volume percent, preferably within a range of 18 to 22 volume percent, with respect to the volume of the starting materials.

[0043] In the vitrified grinding wheel of the present invention, it suffices for at least the portion contributing to grinding to have the above-stated composition. Accordingly, the vitrified grinding wheel of the present invention includes, for example, those in which a vitrified grinding wheel portion containing abrasive grains and vitrified binder is provided on a support surface made of ceramic not containing abrasive grains.

[0044] Further, when the grinding wheel of the present invention is a vitrified superabrasive grain grinding wheel, the additives normally employed in vitrified superabrasive grain grinding wheels, such as embrittling agents and solid lubricants, can be incorporated in suitable quantity as desired.

[Method of manufacturing vitrified grinding wheel]

[0045] The method of manufacturing vitrified grinding wheels of the present invention will be described in greater detail below.

[0046] The manufacturing method of the present invention comprises steps of setting a processing efficiency and a processing precision of grinding, and setting a porosity, a degree of concentration of abrasive grains and an abrasive grain diameter based on the processing efficiency and processing precision. As regards the processing efficiency and processing precision of grinding, porosity, degree of concentration of abrasive grains, and abrasive grain diameter, those regarding the above-described vitrified grinding wheel may be employed without alteration. Further, the abrasive grains, vitrified binder, and pore-forming material employed in the vitrified grinding wheel of the present invention set forth above may be suitably employed as the abrasive grains, vitrified binder, and pore-forming material in the manufacturing method of the present invention.

[0047] The manufacturing method of the present invention may comprise a calcinations step in which a molded product containing at least an abrasive grain, vitrified binder, and a pore-forming material is calcined to burn out the pore-forming material. In the manufacturing method of the present invention, the method of calcining a molded product containing at least an abrasive grain, vitrified binder, and a pore-forming material is preferably one in which the molded product is calcined by maintaining it at a certain temperature for a certain period to burn out the pore-forming material. Such a method is preferable in that the pore-forming material burns out before the vitrified binder melts in the calcination step, preventing calcination shrinkage and disruption of the abrasive grain distribution caused by the binder and abrasive grains moving about freely.

[0048] The period of maintaining mentioned above is preferably long enough for the aforementioned pore-forming material contained in the molded product to burn out. A period adequate for the pore-forming material to burn out can be suitably set based on the shape and dimensions of the grinding wheel being manufactured.

[0049] When maintaining the aforementioned molded product at the calcination temperature of the vitrified binder, it is maintained at a certain temperature falling within the range of the calcination temperature. So long as the temperature remains within this calcination temperature range, variation in the temperature (for example, a rise in temperature over time) is permissible.

[0050] The temperature that is maintained for a certain period during calcination is preferably greater than or equal to the burnout ending temperature of the pore-forming material (preferably a temperature at least 5°C greater than the burnout ending temperature, more preferably a temperature at least 10°C greater than the burnout ending temperature). The temperature of calcining the molded product (maximum temperature during calcination) can be a temperature within the calcination temperature range of the vitrified binder as well as higher than or equal to the burnout ending temperature of the pore-forming material.

[0051] In the manufacturing method of the present invention, the dimension of the molded product in the course of calcining the molded product is preferably a dimension so as to permit adequate burnout of the pore-forming material employed. For example, in the case of a molded product in the form of a rectangular parallelepiped, the thickness (the dimension in which the rectangular parallelepiped is the thinnest) can be set to less than or equal to 10 mm (preferably less than or equal to 5 mm, more preferably less than or equal to 3 mm). As a further example, when the molded product is in the shape of a cylinder, the edge thickness (the thickness of the cylinder wall) can be made less than or equal to 10 mm (preferably less than or equal to 5 mm, more preferably less than or equal to 3 mm).

[0052] In the manufacturing method of the present invention, the atmosphere during calcination is one in which the pore-forming material burns adequately. When the pore-forming material is carbonaceous, an atmosphere containing oxygen can be employed, with air normally being adequate.
[0053] In the manufacturing method of the present invention, the step yielding the molded product can be inserted before the calcination step.
[0054] The molded product is preferably obtained by mixing and stirring starting materials comprising at least abrasive grains, a vitrified binder powder, and a pore-forming material with a primary binder such as an adhesive paste to obtain a mixture in which each of the components has been uniformly dispersed, and molding this mixture by pressing and drying.
[0055] When manufacturing a vitrified superabrasive grain grinding wheel, desired additives such as embrittling agents, solid lubricants, and molding adjuvants that are commonly employed in vitrified superabrasive grain grinding wheels may be incorporated into the above starting materials in suitable quantity.
[0056] The vitrified grinding wheel obtained by the above manufacturing method can be employed as a grinding wheel in various grinding devices. Even when the diameter of the object being ground is small, high processing efficiency and processing precision of grinding are achieved. Thus, it is suited to use in internal grinding. Examples of applications of the grinding wheel of the present invention include grinding of the inner surfaces and sheet surfaces of the injection nozzles of fuel injection devices and pressure regulators, and internal grinding of the inner and outer wheels of bearings.

Examples

[0057] The present invention will specifically described below through Examples.
[0058] Suitable modification of the materials, quantities employed, ratios, processing contents, and processing sequences described in Examples is possible without departing from the spirit of the present invention. Accordingly, the scope of the present invention must not be restrictively interpreted to the specific examples below.

1. Manufacturing of grinding wheel and structure thereof

[0059] Starting materials of the following blend shown in Examples 1 to 3 and Comparative Examples 1 and 2were press molded and calcined in air for 24 hours at 900°C (during which they were maintained at 900°C for one hour) to obtain vitrified grinding wheels. In Example 1, when the decrease in mass was measured under the condition of raising a temperature of 10°C/min, the burnout starting temperature (a reduction of 10 mass percent) of polymethyl methacrylate was found to be 300°C and the burnout ending temperature (a reduction of 90 mass percent) was found to be 500°C. The transition temperature of the vitrified binder employed was 550°C and the specific calcination temperature was 850 to 950°C.

<Starting materials of Example 1 and blend thereof>

cBN abrasive grain (average grain diameter: 30 μm (#600), degree of concentration: 160)	55.1 volume parts
Polymethyl methacrylate (average grain diameter: 30 μm, true specific gravity: 1.2)	17.4 volume parts
Vitrified binder	27.5 volume parts
Adhesive paste	14.5 volume parts

<Structure of grinding wheel of Example 1 after calcination>

cBN abrasive grain		40.0 volume parts
Pore		40.0 volume parts
	Burnout pore (forced pore): 10.0 volume parts	
	Natural pore: 30.0 volume parts	
	Ratio of pores having a size 1 to 3 times the average grain diameter of abrasive grain: 37 volume percent	
Vitrified binder		20.0 volume parts

<Starting materials of Example 2 and blend thereof>

cBN abrasive grain (average grain diameter: 30 μm (#600), degree of concentration: 160)	55.1 volume parts

Table continued

Polymethyl methacrylate (average grain diameter: 5 μm, true specific gravity: 1.2)	17.4 volume parts
Vitrified binder	27.5 volume parts
Adhesive paste	14.5 volume parts

<Structure of grinding wheel of Example 2 after calcination>

cBN abrasive grain		40.0 volume parts
Pore		40.0 volume parts
	Burnout pore (forced pore): 10.0 volume parts	
	Natural pore: 30.0 volume parts	
	Ratio of pores having a size 0.1 to 1 time the average grain diameter of abrasive grain: 67 volume percent	
Vitrified binder		20.0 volume parts

<Starting materials of Example 3 and blend thereof>

cBN abrasive grain (average grain diameter: 30 μm (#600), degree of concentration: 160)	56.5 volume parts
Polymethyl methacrylate (average grain diameter: 5 μm, true specific gravity: 1.2)	21.0 volume parts
Vitrified binder	22.5 volume parts
Adhesive paste	14.5 volume parts

<Structure of grinding wheel of Example 3 after calcination>

cBN abrasive grain		40.0 volume parts
Pore		40.0 volume parts
	Burnout pore (forced pore): 14.0 volume parts	
	Natural pore: 30.0 volume parts	
Vitrified binder		16.0 volume parts

<Starting materials of Comparative Example 1 and blend thereof>

cBN abrasive grain (average grain diameter: 30 μm (#600), degree of concentration: 160)	55.1 volume parts
Carbonaceous beads (150 μm)	17.4 volume parts
Vitrified binder	27.5 volume parts
Adhesive paste	14.5 volume parts

<Structure of grinding wheel of Comparative Example 1 after calcination>

cBN abrasive grain		43.7 volume parts
Pore		40.0 volume parts
	Burnout pore (forced pore): 10.0 volume parts	
	Natural pore: 30.0 volume parts	
Vitrified binder		16.3 volume parts

<Starting materials of Comparative Example 2 and blend thereof>

cBN abrasive grain	69.2 volume parts
(average grain diameter: 30 μm, degree of concentration: 180)	
Vitrified binder	30.8 volume parts
Adhesive paste	14.3 volume parts

<Structure of grinding wheel of Comparative Example 2 after calcination>

cBN abrasive grain	45.0 volume parts
Pore (natural pore)	35.0 volume parts
Vitrified binder	20.0 volume parts

[0060] Figs. 1, 3 and 4 are enlarged schematic cross-sectional views of the structures of the grinding wheels of Example 1 and Comparative Examples 1 and 2 obtained after calcination. As shown in Fig. 1, the grinding wheel of the present invention is a grinding wheel in which cBN abrasive grains 1 are bonded by vitrified binder 3, and burnout pores (forced pores) 2 and natural pores 4 are present. As shown in Fig. 3, the grinding wheel of Comparative Example 1 is a grinding wheel in which cBN abrasive grains 21 and burnout pores 22 are bonded by vitrified binder 23, and pores 24 are present. As shown in Fig. 4, the grinding wheel of Comparative Example 2 is a grinding wheel in which cBN abrasive grains 31 are bonded by vitrified binder 32, and pores 33 are present.

[0061] When the structure of the grinding wheel of the present invention is compared to those of the grinding wheels of Comparative Examples, the grinding wheel of Example 1 shown in Fig. 1 has more uniformly dispersed abrasive grains and pores and greater porosity than the grinding wheels of Comparative Examples 1 and 2. By contrast, the grinding wheel of Comparative Example 1 shown in Fig. 3, despite having good porosity, has nonuniformly dispersed abrasive grains. The grinding wheel of Comparative Example 2 shown in Fig. 4 has nonuniform abrasive grains and low porosity. This reveals that the grinding wheel of the present invention is a grinding wheel having good chip pocket size while maintaining a certain effective cutting edge spacing.

2. Evaluation of vitrified grinding wheel (1)

[0062] The grinding wheels obtained in Example 1 and Comparative Examples 1 and 2 were used to conduct internal grinding and the relation between grinding efficiency ratio and the size of the effective cutting edge spacing was examined. Fig. 7 gives the results. The ground objects, the processing conditions, and the dressing conditions are given below.

<Ground object>

Material	SCM415
Dimension	Internal diameter ϕ 3.95mm
Grinding allowance	ϕ 0.05 mm

<Processing condition>

Machine employed	Grinder for internal grinding
Grinding type	Wet oscillation grinding
Peripheral speed of grinding wheel	22.6 m/s
Peripheral speed of ground object	0.5 m/s
Grinding efficiency ratio	1-3.2
Oscillation	Done
Grinding oil	Oil-based

<Dressing condition>

Dresser	ϕ 50 square column rotary
Dress depth of cut	ϕ 1 μm/pass
Lead	0.004 mm/rev

[0063] In Fig. 7, for an identical effective cutting edge spacing We (0.1 mm), it was possible to conduct normal grinding to a grinding efficiency ratio up to 3.2 in Example 1. By contrast, it was only possible to conduct normal grinding to a grinding efficiency ratio up to 1.9 in Comparative Examples 1 and 2. This reveals that for an identical processing precision of grinding, the vitrified grinding wheel of the present invention affords a processing efficiency of grinding of about 1.7 times that of conventional grinding wheels.

3. Evaluation of vitrified grinding wheel (2)

[0064] Internal grinding was conducted at a processing efficiency of grinding of 0.3 mm^3/(mm sec) with the grinding wheels obtained in Examples 1 to 3 and Comparative Example 2, and the power consumption, surface roughness, and abrasion were examined. The change in power consumption is shown in Fig. 8 (1), the results of surface roughness measurement are shown in Fig. 8 (2), and the results of abrasion measurement are shown in Fig. 8 (3). The grinding wheels obtained in Examples 1 and 2 were used to conduct internal grinding at a grinding efficiency of 0.7 mm^3/(mm • sec), and the power consumption, surface roughness, and abrasion were examined. The change in power consumption is shown in Fig. 9 (1), the results of surface roughness measurement are shown in Fig. 9 (2), and the results of abrasion measurement are shown in Fig. 9 (3). However, the grinding wheel of Comparative Example 2 underwent fusion during processing immediately after dressing, precluding subsequent evaluations.
[0065] The ground objects, the processing conditions, and the dressing conditions are given below.

<Ground object>

Material	SUJ-2
Dimension	Internal diameter ϕ 28.3 mm
Grinding allowance	ϕ 0.36 mm

<Processing condition>

Machine employed	Grinder for internal grinding
Grinding type	Wet oscillation grinding
Peripheral speed of grinding wheel	45 m/s
Peripheral speed of ground object	1.25 m/s
Oscillation	Done
Grinding oil	Water-soluble

<Dressing condition>

Dresser	ϕ 25 square column rotary
Dress depth of cut	ϕ 4 μm/pass
Lead	0.030 mm/rev

(i) Power consumption

As shown in Fig. 8 (1), the grinding wheel of Comparative Example 2 exhibited extremely high power consumption during initial grinding and fused, precluding subsequent grinding. By contrast, as shown in Figs. 8 (1) and 9 (1), the grinding wheels of Examples 1 to 3 exhibited low levels of power consumption that were maintained stably during grinding without fusion, permitting continuous grinding.

(ii) Surface roughness

As shown in Fig. 8 (2), the grinding wheels of Examples 1 to 3 achieved a processing precision of grinding of less than or equal to 0.7 Rz (μm) at a processing efficiency of grinding of 0.3 mm^3/(mm • sec).
Further, as shown in Fig. 9 (2), the grinding wheels of Examples 1 and 2 achieved a processing precision of grinding of less than or equal to 0.8 Rz (μm) at a processing efficiency of grinding of 0.7 mm^3/(mm • sec).

(iii) Abrasion

Comparing Examples 1 and 2 as shown in Figs. 8 (3) and 9 (3), the grinding wheel of Example 2, which had a pore-forming material of smaller diameter (that is, smaller forced pores), had greater strength and thus underwent less abrasion. Comparing Examples 2 and 3, in which a pore-forming material of identical diameter was employed, as shown in Fig. 8 (3), the grinding wheel of Example 2, which contained more binder, was harder and thus underwent less abrasion.

Industrial Applicability

[0066] As set forth above, the vitrified grinding wheel of the present invention has a porosity, degree of concentration of abrasive grains, and abrasive grain diameter that are based on preset processing efficiency and processing precision of grinding. Thus, the grinding wheel of the present invention affords precision processing of roughness of surfaces being processed while improving processing efficiency of grinding, formerly considered to be contradicting indicators of grinding wheels.

[0067] In the method of manufacturing a vitrified grinding wheel of the present invention, the processing efficiency and processing precision of grinding are preset. Based on the processing efficiency and processing precision of grinding, the porosity, degree of concentration of abrasive grains, and abrasive grain diameter are set. Thus, the method of manufacturing of the present invention permits uniform distribution of abrasive grains and pores within the grinding wheel, thereby permitting the manufacturing of grinding wheels affording both processing efficiency and processing precision of grinding.

Claims

1. A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, **characterized by** having a porosity, a degree of concentration of abrasive grains and an abrasive grain diameter based on the preset processing efficiency and processing precision of grinding.

2. The vitrified grinding wheel according to claim 1, wherein, when said processing precision of grinding ranges from 0.1 to 1.6 Rz (μ m), the processing efficiency of grinding ranges from 0.1 to 2.0 $mm^3/(mm \cdot sec)$.

3. The vitrified grinding wheel according to claim 1 or 2, wherein said porosity ranges from 30 to 70 volume percent with respect to the volume of the whole grinding wheel.

4. The vitrified grinding wheel according to any of claims 1 to 3, wherein said porosity comprises a forced porosity based on burnout pores formed by burning out a pore-forming material.

5. The vitrified grinding wheel according to claim 4, wherein said forced porosity ranges from 5 to 35 volume percent with respect to the volume of the whole grinding wheel.

6. The vitrified grinding wheel according to claim 4 or 5, wherein said pore-forming material has a size 0.1 to 3 times the average grain diameter of the abrasive grain.

7. The vitrified grinding wheel according to any of claims 1 to 6, wherein the ratio of pores having a size 1 to 3 times the average grain diameter of the abrasive grain in the volume of whole pores ranges from 20 to 70 volume percent.

8. The vitrified grinding wheel according to any of claims 1 to 6, wherein the ratio of pores having a size 0.1 to 1 time the average grain diameter of the abrasive grain in the volume of whole pores ranges from 30 to 70 volume percent.

9. The vitrified grinding wheel according to any of claims 4 to 8, wherein said pore-forming material is a polymer compound.

10. The vitrified grinding wheel according to any of claims 1 to 9, wherein said abrasive grain has an average grain diameter ranging from 10 to 90 μm.

11. The vitrified grinding wheel according to any of claims 1 to 10, wherein said degree of concentration of abrasive grains ranges from 50 to 160.

12. The vitrified grinding wheel according to any of claims 1 to 11, wherein said abrasive grain is a cubic boron nitride abrasive grain.

13. A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, wherein the ratio of pores having a size 1 to 3 times the average grain diameter of the abrasive grain in the volume of whole pores ranges from 20 to 70 volume percent.

14. A vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, wherein the ratio of pores having a size 0.1 to 1 time the average grain diameter of the abrasive grain in the volume of whole pores ranges from 30 to 70 volume percent.

15. The vitrified grinding wheel according to claims 13 or 14, wherein said abrasive grain has an average grain diameter ranging from 10 to 90 μm.

16. The vitrified grinding wheel according to any of claims 13 to 15, wherein the degree of concentration of said abrasive grains ranges from 50 to 160.

17. A method of manufacturing a vitrified grinding wheel comprising at least an abrasive grain and a vitrified binder, comprising steps of;
setting a processing efficiency and a processing precision of grinding, and
setting a porosity, a degree of concentration of abrasive grains and an abrasive grain diameter based on the processing efficiency and processing precision.

18. The method of manufacturing according to claim 17, wherein said processing precision of grinding is set within a range of 0.1 to 1.6 Rz (μm) and said processing efficiency of grinding is set within a range of 0.1 to 2.0 $mm^3/(mm \bullet sec)$.

19. The method of manufacturing according to claim 17 or 18, wherein said porosity is set within a range of 30 to 70 volume percent with respect to the volume of the whole grinding wheel.

20. The method of manufacturing according to any of claims 17 to 19, wherein said porosity comprises a forced porosity based on burnout pores formed by burning out a pore-forming material.

21. The method of manufacturing according to claim 20, wherein said forced porosity is set within a range of 5 to 35 volume percent with respect to the volume of the whole grinding wheel.

22. The method of manufacturing according to claim 20 or 21, wherein a pore-forming material having a size 0.1 to 3 times the average grain diameter of the abrasive grain is employed as said pore-forming material.

23. The method of manufacturing according to any of claims 17 to 22, wherein a polymer compound is employed as said pore-forming material.

24. The method of manufacturing according to any of claims 17 to 23, wherein an abrasive grain having an average grain diameter ranging from 10 to 90 μm is employed as said abrasive grain.

25. The method of manufacturing according to any of claims 17 to 24, wherein said degree of concentration of abrasive grains is set within a range of 50 to 160.

26. The method of manufacturing according to any of claims 17 to 25, wherein a cubic boron nitride abrasive grain is employed as said abrasive grain.

Fig. 1

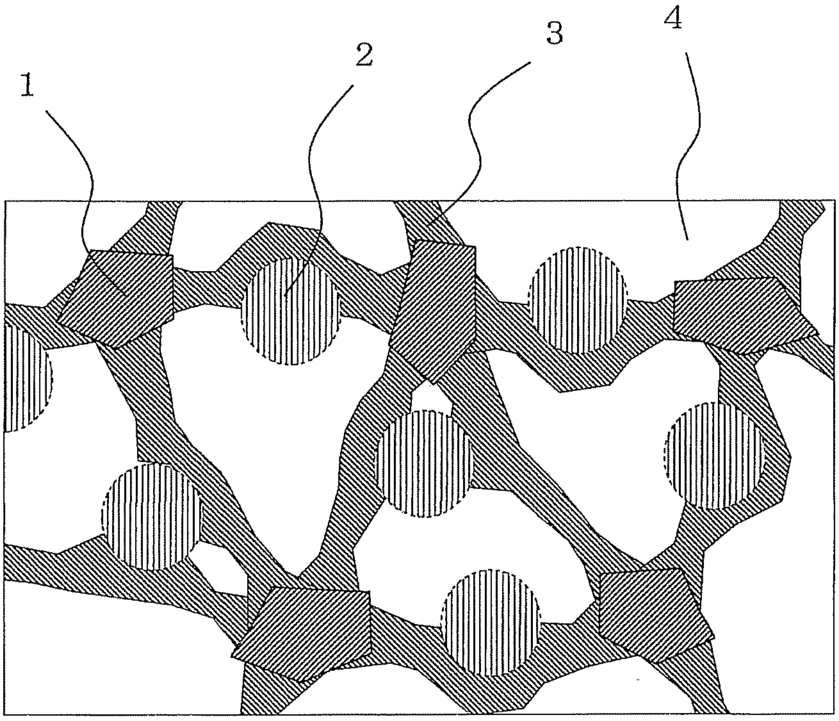


Fig. 2

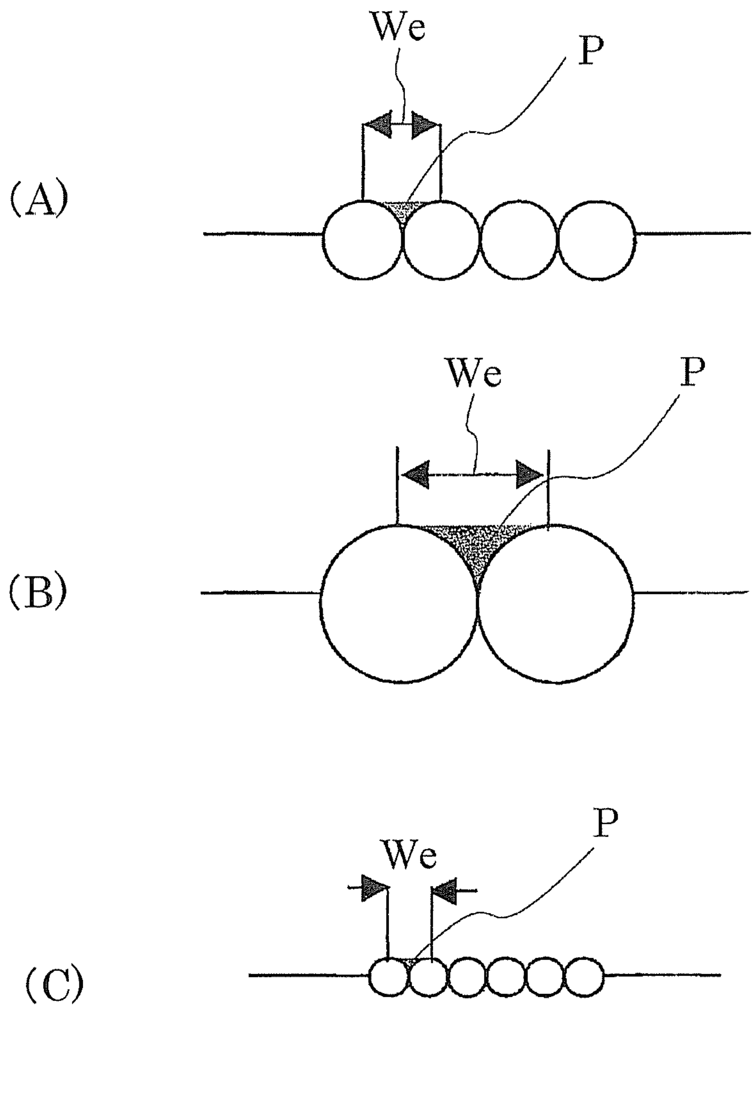


Fig. 3

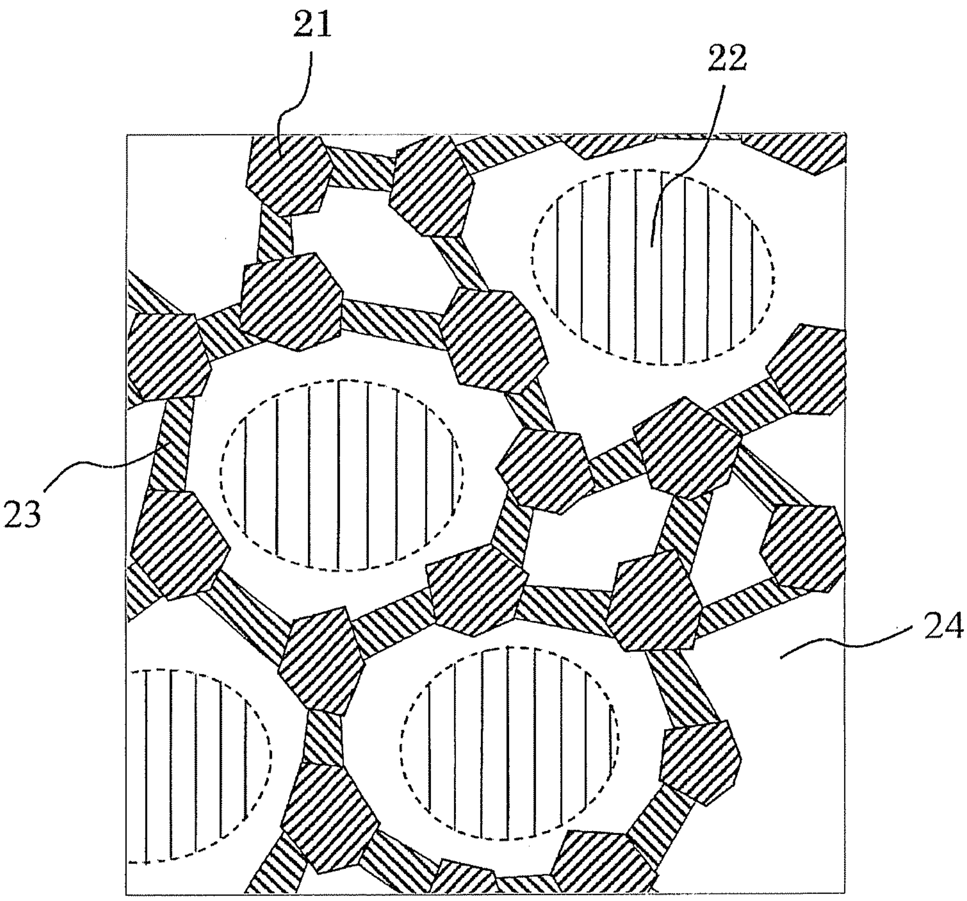


Fig. 4

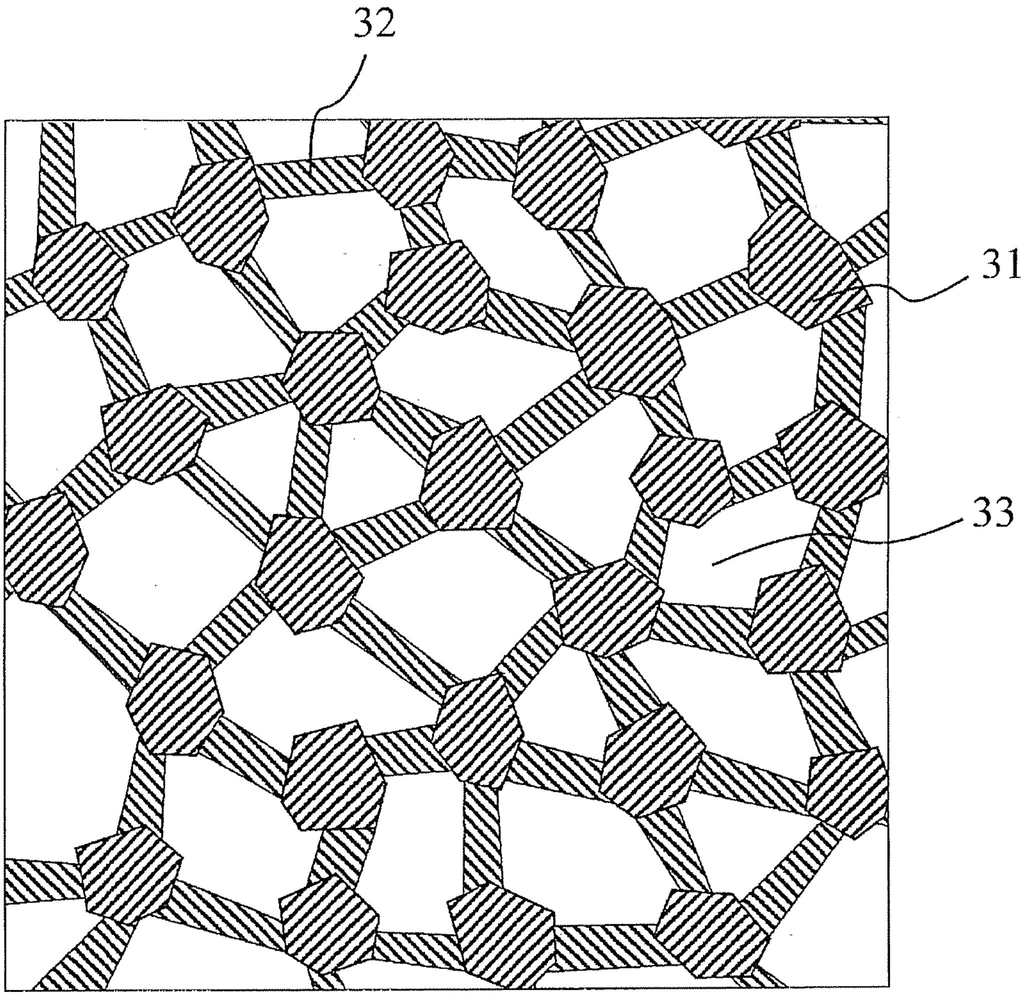


Fig. 5

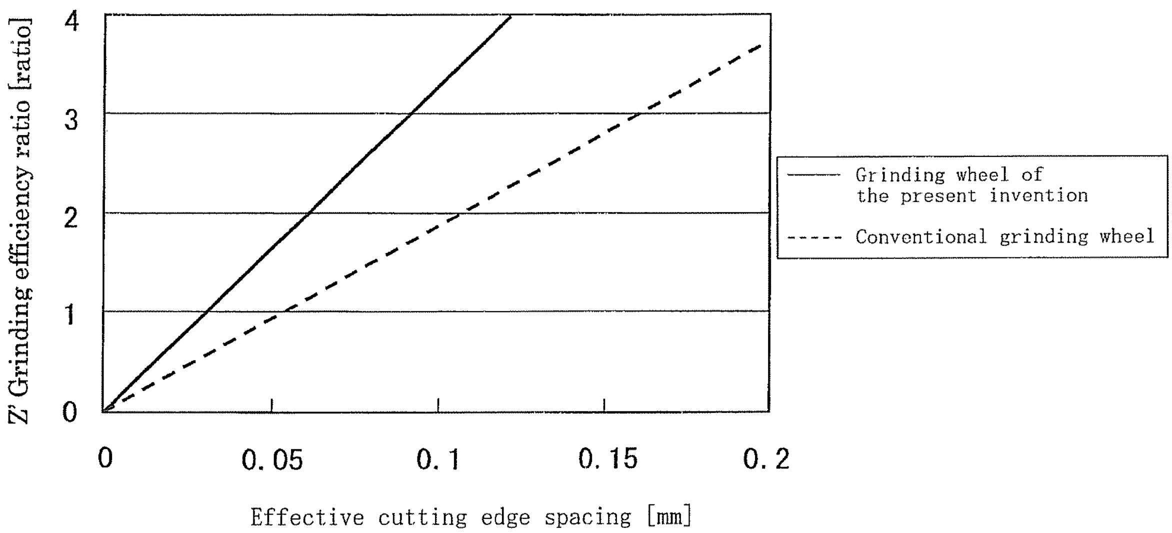

Z' Grinding efficiency ratio [ratio]
4
3
2
1
0
0
0.05
0.1
0.15
0.2
Effective cutting edge spacing [mm]
Grinding wheel of the present invention
Conventional grinding wheel

Fig. 6

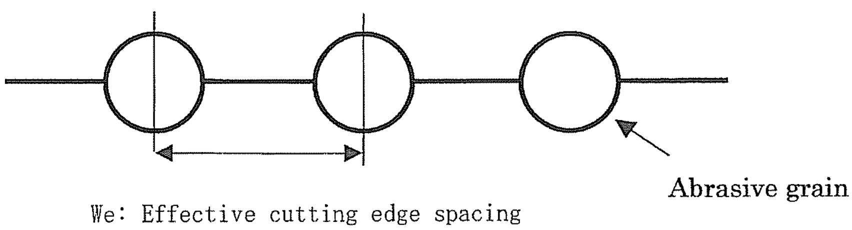

Abrasive grain
We: Effective cutting edge spacing

Fig. 7

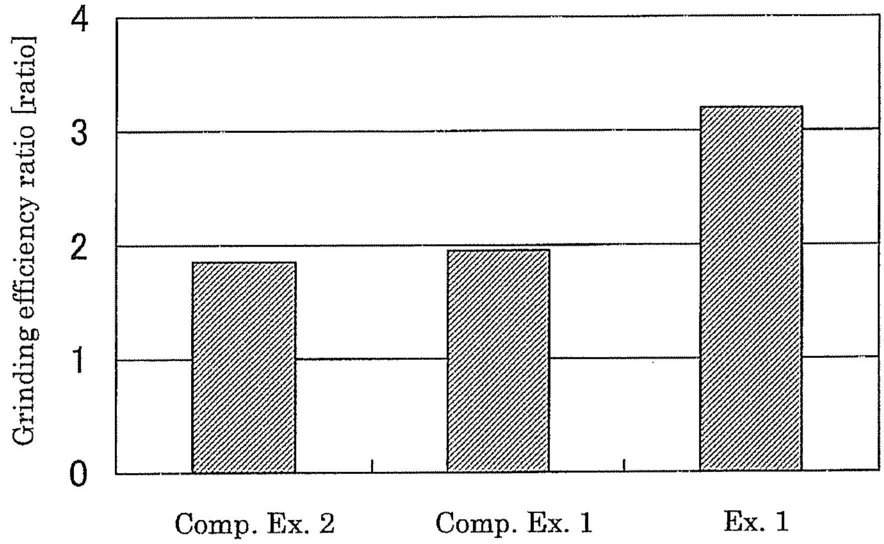

Grinding efficiency ratio [ratio]
4
3
2
1
0
Comp. Ex. 2
Comp. Ex. 1
Ex. 1

Fig. 8 (1)

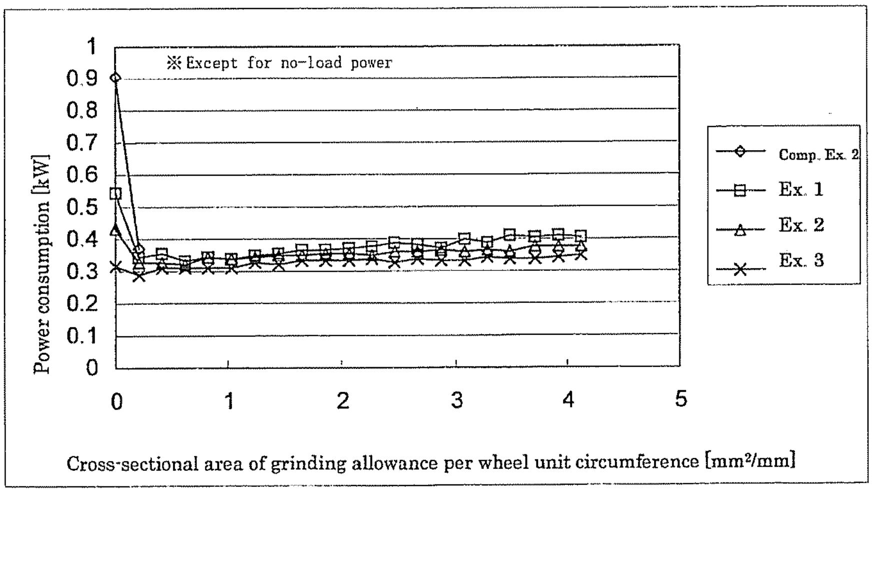

※Except for no-load power
Power consumption [kW]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
Comp. Ex. 2
Ex. 1
Ex. 2
Ex. 3
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]

Fig. 8 (2)

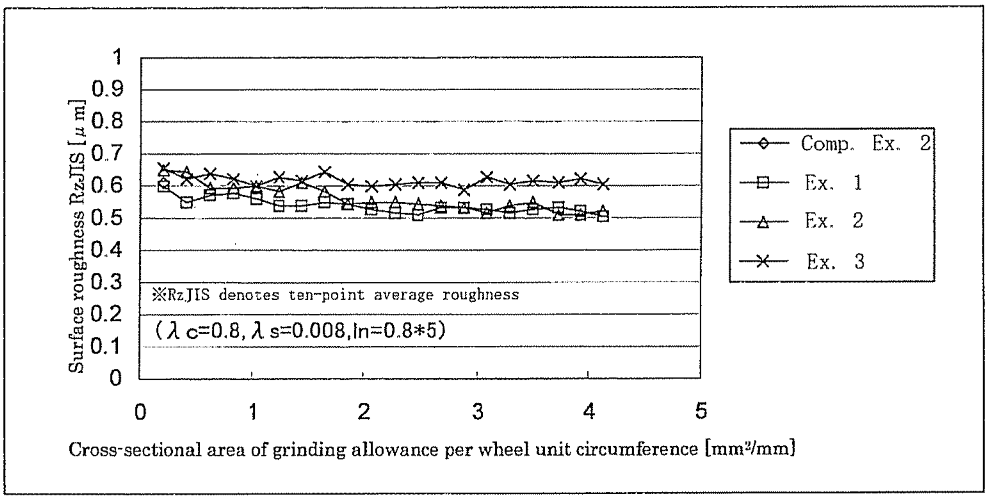

Surface roughness RzJIS [μ m]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
※RzJIS denotes ten-point average roughness
(λ c=0.8, λ s=0.008, ln=0.8*5)
0
1
2
3
4
5
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]
Comp. Ex. 2
Ex. 1
Ex. 2
Ex. 3

Fig. 8 (3)

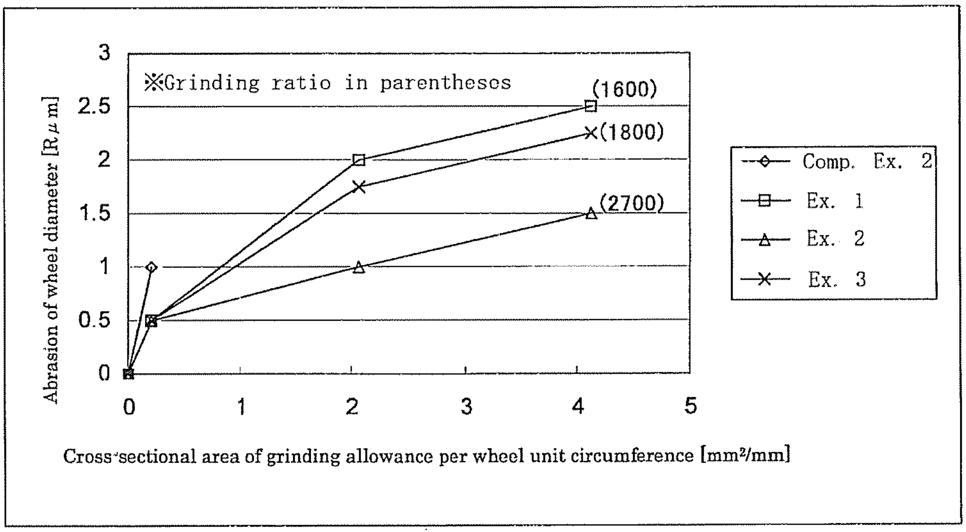

Abrasion of wheel diameter [R μ m]
3
2.5
2
1.5
1
0.5
0
※Grinding ratio in parentheses
(1600)
(1800)
(2700)
0
1
2
3
4
5
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]
Comp. Ex. 2
Ex. 1
Ex. 2
Ex. 3

Fig. 9 (1)

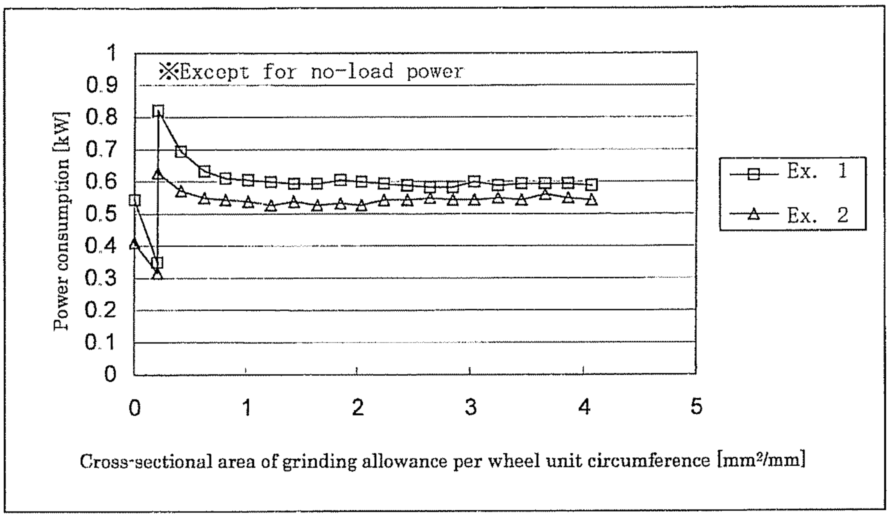

※Except for no-load power
Power consumption [kW]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
Ex. 1
Ex. 2
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]

Fig. 9 (2)

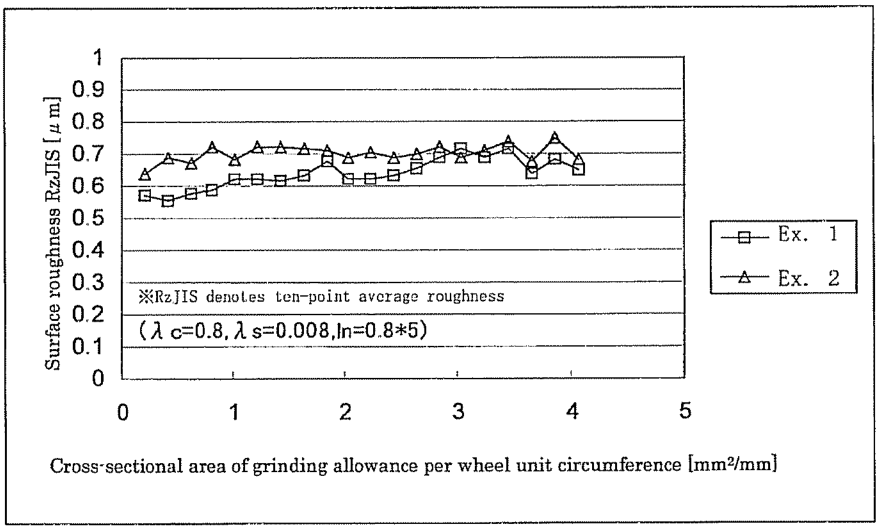
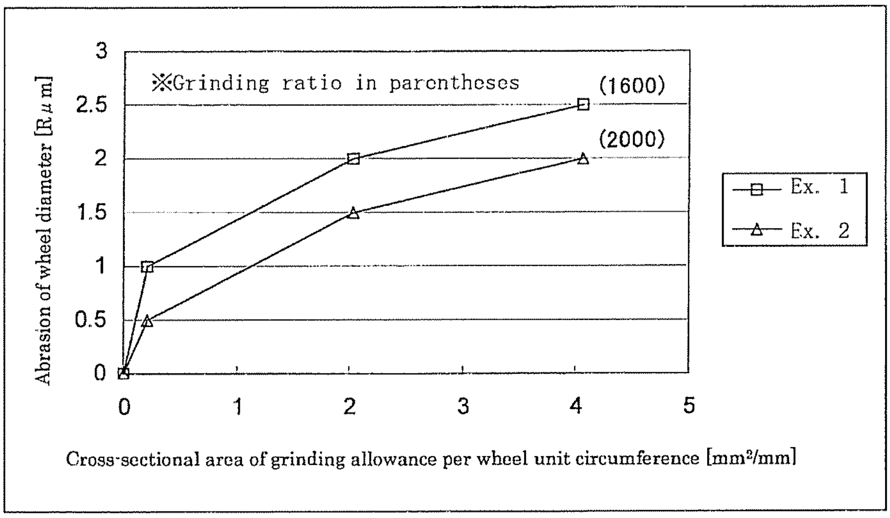

Surface roughness RzJIS [μm]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
※RzJIS denotes ten-point average roughness
(λc=0.8, λs=0.008, ln=0.8*5)
Ex. 1
Ex. 2
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]

Fig. 9 (3)



※Grinding ratio in parentheses
(1600)
(2000)
Ex. 1
Ex. 2
Abrasion of wheel diameter [Rμm]
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
Cross-sectional area of grinding allowance per wheel unit circumference [mm²/mm]

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2004/007754

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 B24D3/18

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^7 B24D3/00-3/34

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

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-2004
Kokai Jitsuyo Shinan Koho	1971-2004	Jitsuyo Shinan Toroku Koho	1996-2004

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2002-224963 A (A.L.M.T. Corp.), 13 August, 2002 (13.08.02), Full text; all drawings (Family: none)	1-26
Y	JP 2003-136410 A (A.L.M.T. Corp.), 14 May, 2003 (14.05.03), Full text; all drawings (Family: none)	1-26
Y	JP 10-138148 A (Noritake Co., Ltd.), 26 May, 1998 (26.05.98), Full text; all drawings (Family: none)	1-26

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 August, 2004 (19.08.04)	07 September, 2004 (07.09.04)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/007754

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2000-317844 A (Noritake Co., Ltd.), 21 November, 2000 (21.11.00), Full text; all drawings (Family: none)	1-26
Y	JP 9-300222 A (Yugen Kaisha JGI), 25 November, 1997 (25.11.97), Par. Nos. [0015], [0016]; Figs. 1, 2 (Family: none)	8,14

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