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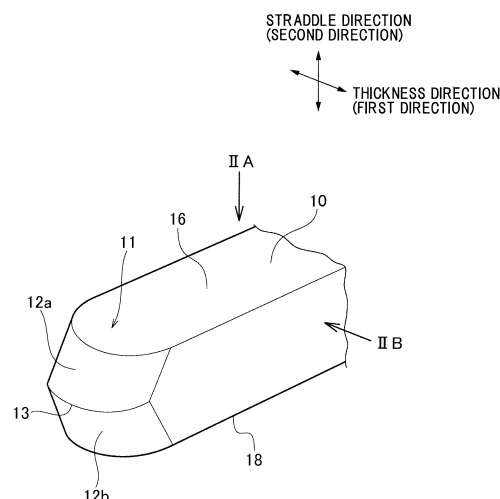
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(54) **SUPERFINISHING WHETSTONE, SUPERFINISHING METHOD USING SAME, AND BALL BEARING**

(57) A whetstone (10) is provided with a first slope (12a) and a second slope (12b) at the head (11) thereof. When viewed in the thicknesswise direction, these slopes (12a, 12b) extend from the center of the whetstone toward the both sides thereof at an inclination angle of 3 to 5° to the crosswise (widthwise) direction, and meet in a nearly V-shaped state. The first and second slopes (12a, 12b) have an arc-shaped contour as viewed in the crosswise direction. The whetstone (10) is obtained by binding composite abrasive grains with a vitrified bond, said composite abrasive grains comprising: soft abrasive grains which are chemically reactive with a material to be cut and which do not cut the material; and hard abrasive grains which can cut the material.

FIG. 1



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a superfinishing stone for the superfinishing of materials to be machined, in particular, a superfinishing stone suitable for superfinishing the raceway grooves of ball bearings, and to a superfinishing method using the stone and a ball bearing.

BACKGROUND ART

10 **[0002]** For superfinishing the raceway surfaces of ball bearings, superfinishing machines for exclusive use are generally used. In cases when the raceway groove of the inner ring or outer ring of a ball bearing is superfinished with such a superfinishing machine, the inner ring or outer ring is rotated and a stone held by the stone holder is pressed against the raceway groove and rocked. The stone is thereby reciprocated along the raceway groove within a certain range of
15 angles to superfinish the groove. The superfinishing stone in this machining does not undergo a stone shaping step, such as truing or dressing, in preparation for the processing, unlike stones in grinding. It is therefore necessary that the shape of the working surface of the stone should be regulated beforehand so as to conform to the circular-arc curved surface of the raceway groove to be processed.

20 **[0003]** The raceway grooves of the ball bearing have been processed beforehand by grinding which precedes the superfinishing, so as to have a circular-arc cross-section. In the superfinishing, the raceway groove is efficiently mirror-finished, for example, to an Ra of 0.01 μm less in a short time period while maintaining the accuracy of the shape formed by the pre-processing grinding.

25 **[0004]** During the processing, the stone in contact with the raceway groove is pushed out of the stone holder just in an amount corresponding to the wear loss of the stone, without discontinuing the processing each time the stone has worn. Thus, the position thereof is always corrected. In the superfinishing of a ball bearing, when the works to be
30 processed are the inner ring and the outer ring, then the outer circumferential surface and the inner circumferential surface, respectively, are superfinished using the respective processing modes.

[0005] In a conventional technique for superfinishing an outer-ring raceway groove, use is made of a stone 100 which has, in a tip part thereof, a protrudent circular-arc surface 101 having a radial dimension corresponding to the circular-arc curved surface of the raceway groove, as shown in, for example, Fig. 7. This superfinishing has been conducted in the following manner. As shown in Figs. 9A and 9B, the stone 100 is disposed so that the protrudent circular-arc surface 101 conforms to the outer-ring raceway groove 3 of the outer ring 2, and the outer-ring raceway groove 3 is superfinished while rotating the outer ring 2 and rocking the stone 100 along the direction of the rotation axis of the outer ring 2.

35 **[0006]** Meanwhile, patent document 1 describes a feature wherein, as shown in Fig. 8, a tip part of a stone 200 is made to have a shape configured of: a cylindrical surface portion 201 having a radius of curvature slightly larger than the radius of curvature of the raceway groove of the outer ring; and tapered portions 202 which extend respectively to both sides of the cylindrical surface portion 201 along the axial direction thereof. This shape of the stone 200 brings about a decrease in the area of contact between the outer-ring raceway groove and the stone, resulting in an increase in surface pressure to render the abrasive grains apt to shed. Thus, the shape of the stone comes, in a short period, to conform to the shape of the outer-ring raceway groove and the so-called hit comes to continue. The document states that as a result, the work has no portion left unremoved by the grinding and need not be discarded or reprocessed as a defective due to accuracy failure and that the first bearing processed just after stone replacement can be a non-defective product.

45 **[0007]** Besides patent document 1, a plurality of prior-art documents concerning stones are known (patent documents 2 to 6).

RELATED ART REFERENCE

PATENT DOCUMENT

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[0008]

Patent Document 1: Japanese Utility Model Registration No. 2600506

Patent Document 2: JP-A-2006-130635

55 Patent Document 3: JP-A-5-329780

Patent Document 4: JP-UM-A-57-189774

Patent Document 5: JP-UM-A-59-12561

Patent Document 6: JP-UM-A-3-130367

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0009] However, the stone described in any of the prior-art documents is unsatisfactory in terms of the ability to be conformed (hereinafter referred to also as conformability), and there has been room for improvement. In superfinishing, the conforming operation which is performed by means of the work at the time when a new stone is used first has various problems including a decrease in production efficiency in mass-production steps and the occurrence of percent defective due to insufficient formation of a stone working surface.

[0010] Meanwhile, use of abrasive grains having high friability or a soft superfinishing stone is thought to be effective in improving the conformability of stones. In this case, however, stone wear is enhanced, resulting in an undesirable deformation of the stone shape or a shortened stone life. Consequently, desired surface accuracy is not obtained, and stone replacement becomes necessary after only a limited amount of processed products are produced.

[0011] Vitrified-bond stones which employ superhard cubic boron nitride (CBN) abrasive grains or diamond (SD) abrasive grains are increasingly being put to practical use as superfinishing stones in place of the conventional stones employing white aluminum oxide (WA) abrasive grains or green silicon carbide (GC) abrasive grains.

[0012] Especially for bearing steels, vitrified stones containing superhard abrasive grains are extensively selected. However, superhard abrasive grains are expensive as compared with WA or GC abrasive grains and, hence, the stones are required to have such quality that the wear resistance is high or the stone life is long. As a result, the amount of stone wear is extremely slight. For example, the amount of stone wear per work is as small as 1 μm or less; in the case of WA or GC stones, the wear amount thereof is 20-30 times.

[0013] Consequently, especially for superfinishing in which superhard abrasive grains are used, conformability, which is required in preparation for processing, is an important subject. Even in cases when the working surface of a stone has been regulated to a complete three-dimensional shape, the center of the circular arc of the raceway groove formed by pre-processing grinding, in the state of having been attached to a superfinishing machine, does not always coincide with the center line of the stone. In case where even a slight offset has occurred, there is a possibility that the stone might suffer a deformation, chipping, etc., resulting in a decrease in superfinishing accuracy or efficiency.

[0014] There have been cases where the occurrence of an offset with respect to the positional relationship between a work and a stone in stone replacement results in the necessity of using 10-20 works for conforming per, for example, stone working surface area of 10-15 mm^2 in the case of vitrified stones containing superhard abrasive grains, although the number thereof depends on the size of the stone (size of the stone working surface).

[0015] An object of the invention, which has been achieved in view of the circumstances described above, is to provide a superfinishing stone which can be easily conformed to works to be machined, a superfinishing method in which the stone is used, and a ball bearing.

MEANS FOR SOLVING THE PROBLEMS

[0016] The present inventors have found out a superfinishing stone which satisfies inconsistent stone requirements, i.e., stone quality that brings about improved conformability and finishing performance, and further found out a superfinishing method in which this stone is used. The invention has been thus achieved. That object of the invention is accomplished with the following configurations.

(1) A superfinishing stone characterized by being equipped at a tip part thereof with a first inclined surface and a second inclined surface which, when viewed from a first direction, extend from a central portion respectively toward both sides at an inclination angle of 3° - 5° with a second direction that is perpendicular to the first direction and meet each other approximately in the shape of the letter V,

the first inclined surface and the second inclined surface each having the shape of a circular arc when viewed from the second direction, and

by having been obtained by binding composite abrasive grains with a vitrified bond, the composite abrasive grains including soft abrasive grains which have chemical reactivity with a material to be machined but do not have abrasive properties thereagainst and hard abrasive grains which have abrasive properties against the material to be machined.

(2) The superfinishing stone according to (1) characterized in that when the second-direction length which is the length along the second direction is expressed by B (mm) and the inclination angle of the first inclined surface and the second inclined surface is expressed by α ($^\circ$), then the maximum conforming amount d represented by the following equation (1) is 0.13-0.22 mm.

$$d=(B/2)\times\tan\alpha \quad (I)$$

(3) The superfinishing stone according to (1) or (2) characterized in that the composite abrasive grains include 10-40% the soft abrasive grains and 60-90% the hard abrasive grains, in terms of volume ratio in the mixture.

(4) The superfinishing stone according to any one of (1) to (3) characterized in that the hard abrasive grains are hard abrasive grains of at least one kind selected from abrasive grains of cubic boron nitride and abrasive grains of diamond and

the soft abrasive grains are soft abrasive grains of one or more kinds selected from cerium oxide, barium sulfate, silicon oxide, and zirconium oxide.

(5) A superfinishing method which includes superfinishing the outer-ring raceway groove of the outer ring of a ball bearing using the superfinishing stone according to any one of (1) to (4), the method being characterized in that the superfinishing stone is disposed so that the first direction is parallel with the direction of the rotation axis of the outer ring and the second direction coincides with the circumferential direction of the outer ring and an operation for conforming the superfinishing stone is performed before the superfinishing operation at a pressure which is $90\pm5\%$ of the critical stone pressure.

(6) The superfinishing method according to (5) characterized in that the superfinishing operation is conducted at a stone surface pressure which is lower than the pressure used in the conforming operation.

(7) A ball bearing equipped with an inner ring, an outer ring, and a plurality of balls disposed between the inner ring and the outer ring in a freely rollable manner, the ball bearing being characterized in that the outer-ring raceway groove of the outer ring has been superfinished by the superfinishing method according to (5) or (6).

ADVANTAGE OF THE INVENTION

[0017] According to the invention, the shape of the stone working surface in the tip part is configured of a first inclined surface and a second inclined surface which meet each other approximately in the shape of the letter V. Consequently, the portion which comes into strong contact with the surface to be machined has an increased contact area, while the portion which comes into weak contact therewith has a reduced contact area. As a result, the stone working surface comes to undergo an overall hit and have improved conformability with a minimum number of works required for conforming. Furthermore, by dispersedly disposing soft abrasive grains, a lubricant layer which is non-abrasive, soft, and weak but is less apt to shed is formed, resulting in a further improvement in conformability and a reduction in stone wear amount. Thus, the inconsistent stone requirements, i.e., stone quality that brings about improved conformability and finishing performance, can be simultaneously satisfied.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018]

Fig. 1 is a slant view of the tip part of a superfinishing stone according to one embodiment of the invention.

Fig. 2A is a view of the tip part of the superfinishing stone viewed from the straddle direction (IIA of Fig. 1), and Fig. 2B is a view of the tip part of the superfinishing stone viewed from the thickness direction (IIB of Fig. 1).

Fig. 3 is a view of the tip part of a superfinishing stone according to an embodiment of the invention produced using a rotary dresser, the tip part being viewed from the thickness direction.

Figs. 4A and 4B are views which illustrate a method for producing the superfinishing stone of Fig. 3 using a rotary dresser; Fig. 4A is a view which illustrates first plunge processing, and Fig. 4B is a view which illustrates second plunge processing.

Fig. 5 is a view which illustrates an operation for conforming to the outer-ring raceway groove of the outer ring of a ball bearing, in which a superfinishing stone produced by the production process of Fig. 1 is used.

Figs. 6A to 6E are views which show photographs of the working surfaces of test stones; Fig. 6A shows the case of BaSO_4 abrasive grains, Fig. 6B shows the case of CeO_2 abrasive grains, Fig. 6C shows the case of ZrO_2 abrasive grains, Fig. 6D shows the case of SiO_2 abrasive grains, and Fig. 6E shows the case of CBN abrasive grains.

Fig. 7 is a slant view of the tip part of a conventional superfinishing stone.

Fig. 8 is a slant view of the tip part of the superfinishing stone described in patent document 1.

Figs. 9A and 9B are views which illustrate an operation for superfinishing the outer-ring raceway groove of the outer ring of a ball bearing using a conventional superfinishing stone; Fig. 9A is a cross-sectional view taken on the line A-A of Fig. 9B, and Fig. 9B is a view, viewed from the axial direction.

Fig. 10 is a view which shows the state of the stone working surface of a superfinishing stone which is undergoing an overall hit.

MODES FOR CARRYING OUT THE INVENTION

[0019] With respect to the state of contact between a work surface to be machined and a stone working surface, the present inventors directed attention to that portion of the stone which comes into strong contact with the surface to be machined and that portion thereof which comes into weak contact with the surface. The portion which comes into strong contact is prone to suffer clogging in the case where the stone acts hard, but suffers an increased stone wear amount in the case where the stone acts softly. The inventors hence have found that the conformability of a stone, i.e., the conformability of the whole area of the stone working surface, is improved by increasing the area of the stone working surface of that portion of the stone which comes into strong contact and by reducing the area of the stone working surface of that portion of the stone which comes into weak contact. In the invention, that portion of the stone in which the stone working surface comes into strong contact with surfaces to be machined has been made to have enhanced stone conformability, and the conformability of the whole stone working surface has been improved thereby.

[0020] The stone working surface of a stone for superfinishing outer-ring raceway grooves acts in the following manner. A stone central portion thereof, which is shown as the hatched part in Fig. 10, comes into continuous strong contact, while the peripheral portions, i.e., the portions other than the stone central portion, come into intermittent weak contact. Consequently, by increasing the stone contact area of the central portion of a stone, the conformability of the stone is improved.

[0021] A superfinishing stone according to one embodiment of the invention, which was produced on the basis of the technical idea described above, is explained below in detail by reference to drawings.

[0022] Fig. 1 is a slant view of the tip part of a superfinishing stone according to one embodiment of the invention; and Fig. 2A is a view of the tip part of the superfinishing stone viewed from the straddle direction (IIA of Fig. 1), and Fig. 2B is a view of the tip part of the superfinishing stone viewed from the thickness direction (IIB of Fig. 1).

[0023] The superfinishing stone 10 (hereinafter referred to simply as stone 10) according to this embodiment is equipped at a tip part 11 thereof with a first inclined surface 12a and a second inclined surface 12b which, when one of two perpendicular directions is referred to as thickness direction (direction IIB in Fig. 1) and the other is referred to as straddle direction (direction IIA in Fig. 1) and when the surfaces are viewed from the thickness direction, extend from a central portion respectively toward both sides at an inclination angle α with the straddle direction (see Fig. 2B). The first inclined surface 12a and the second inclined surface 12b meet each other at the straddle-direction central portion to form a ridge 13. The ridge 13 has a sharp approximately letter-V shape so that the straddle width gradually decreases toward the tip. Incidentally, the thickness direction corresponds to the direction of the rotation axis of the outer ring 2 of a ball bearing in an operation for superfinishing the outer-ring raceway groove 3 of the outer ring 2 (the operation includes a conforming operation; the same applies hereinafter), while the straddle direction corresponds to the circumferential direction in the operation for superfinishing the outer-ring raceway groove 3 of the ball-bearing outer ring 2 (see Fig. 5).

[0024] As shown in Fig. 2A, the first inclined surface 12a and the second inclined surface 12b each have the shape of a circular arc when viewed from the straddle direction. More specifically, the tip part of the first inclined surface 12a has a circular-arc shape when viewed from one straddle direction, while the tip part of the second inclined surface 12b has a circular-arc shape when viewed from the other straddle direction. The curvature of the circular-arc shape is set in accordance with the work to be machined. In cases when the outer-ring raceway groove of the outer ring of a ball bearing is to be superfinished, the curvature of the circular-arc shape is set so as to be approximately equal to that of the circular arc of the outer-ring raceway groove.

[0025] Here, the inclination angle α is set at 3°-5°. By setting the inclination angle α at 3°-5°, the tip part 11 is rendered closely akin in shape to the outer-ring raceway groove and the stone contact area is increased, thereby improving the conformability. In case where the inclination angle α is less than 3°, the effect of forming an inclined surface is too low. In case where the inclination angle exceeds 5°, the maximum conforming amount, which is explained below, becomes too large and much time is required for the tip part to have a circular-arc shape that conforms to the outer-ring raceway groove. The inclination angle α is preferably 3.5°-4.5°, more preferably about 4°.

[0026] In cases when the straddle width which is the straddle-direction width of the tip part 11 is expressed by B, the inclination amount in the tip part 11, i.e., the maximum conforming amount d (mm) in a central portion of the stone, is expressed by the following equation (I).

$$d=(B/2)\times\tan\alpha \quad (I)$$

[0027] Consequently, as the inclination angle α in the tip part 11 having a constant straddle-direction width B increases,

the maximum conforming amount d becomes larger in proportion thereto. Although the maximum conforming amount d has suitable values, it is necessary to reduce the inclination angle α as the straddle-direction width B increases. Conversely, it is necessary that as the straddle-direction width B decreases, the inclination angle α should be increased. In general, the conforming operation is easy when the stone working area is less than 10 mm^2 , and is not easy when the area is 10 mm^2 or larger. The maximum conforming amount d is preferably $0.13\text{--}0.22 \text{ mm}$, more preferably about 0.175 mm .

[0028] As a result, the stone central portion, of the stone working surface, that is always in contact with the surface being processed undergoes accelerated wear, and this not only increases the area of the stone working surface but also rapidly conforms the whole stone. Hitherto, there have been cases where even when the working surface of a stone has been regulated to a complete three-dimensional shape, the center of the circular arc of the raceway groove of an outer ring formed by pre-processing grinding, in the state of having been attached to a superfinishing machine, does not always coincide with the center line of the stone. There has been a possibility that the occurrence of even a slight offset might make the stone suffer a deformation, chipping, etc., resulting in troubles such as a decrease in superfinishing accuracy or efficiency, etc.

[0029] In the invention, that part of the stone working surface which comes into strong contact with the surface to be machined has been made to have an increased stone working surface area and to undergo accelerated stone wear. Consequently, a conformed stone surface can be stably formed with high accuracy, and it is possible to bring the work and the stone into a properly set state even in cases when an offset has occurred.

[0030] The tip part 11 of this stone 10 can be shaped with a rotary dresser. Figs. 4A and 4B show an example of shaping methods for shaping the tip part 11 of a stone 10 with a rotary dresser.

[0031] First, a stone 10 is disposed so that the center line Y thereof is offset from a perpendicular line X which is perpendicular to the central axis O of a rotary dresser 50. Specifically, while the center line Y of the stone 10 is kept parallel with the perpendicular line X , the stone 10 is disposed in such a position that the center line Y has shifted upward in the straddle direction by a distance equal to, for example, a half ($T/2$) of the straddle width (T) of the stone 10. This offset amount is set so that the first inclined surface 12a to be formed has an inclination angle of $3^\circ\text{--}5^\circ$. The stone 10 in this state is moved parallel with the perpendicular line X toward the rotary dresser 50 and pressed against a dressing groove 51 of the rotary dresser 50, thereby shaping the tip part. Thus, first plunge processing is conducted. By this processing, that surface 16 of the tip part 11 of the stone 10 which is on one side is shaped into a circular-arc shape and a first inclined surface 12a is formed in the tip part 11 on said one side.

[0032] Subsequently, the stone 10 is reversed with respect to the straddle direction, and this stone 10 is disposed in the same position relative to the rotary dresser 50. Namely, the stone 10 is disposed so that the center line Y of the stone 10 coincides with the position shifted upward in the straddle direction from the perpendicular line X perpendicular to the central axis O of the rotary dresser 50 by a distance equal to a half ($T/2$) of the straddle width (T) of the stone 10. As a result of the reversal of the stone 10, the first inclined surface 12a faces upward with respect to the straddle direction, and the surface 18 on the other side, which has not been shaped, faces downward and is disposed near the rotary dresser 50. This offset amount also is set so that the second inclined surface 12b to be formed has an inclination angle of $3^\circ\text{--}5^\circ$ and that this inclination angle is equal to that of the first inclined surface 12a. The grinding stone 10 in this state is moved parallel with the perpendicular line X toward the rotary dresser 50 and pressed against the dressing groove 51 of the rotary dresser 50, thereby shaping the tip part. Thus, second plunge processing is conducted. By this processing, that surface 18 of the tip part 11 of the stone 10 which is on the other side is also shaped into a circular-arc shape and a second inclined surface 12b is formed in the tip part 11 on said other side. Thus, a stone 10 is produced.

[0033] In the stone 10 produced using a rotary dresser in the manner shown above, the first inclined surface 12a and the second inclined surface 12b are curved so as to be slightly recessed due to the curvature of the rotary dresser, as shown in Fig. 3. The inclination angles α in this case are, as shown in Fig. 3, the angle formed by the straddle direction and a line which connects the top of the ridge 13 to the end of the one-side surface 16 and the angle formed by the straddle direction and a line which connects the top of the ridge 13 to the end of the other-side surface 18, when the tip part 11 is viewed from the thickness direction.

[0034] The composition of the stone 10 is then explained.

(1) Composition and Production Process

[0035] The stone 10 is a composite-superabrasive-grain vitrified-bond stone obtained by binding composite superabrasive grains including soft abrasive grains having no abrasive properties and hard abrasive grains having abrasive properties, with a vitrified bond.

[0036] The hard abrasive grains are cubic boron nitride (CBN), diamond (SD) (each having a new Moh's hardness of 14 or 15), etc. The soft abrasive grains are cerium oxide (CeO_2 ; hardness, 4-5), barium sulfate (BaSO_4 ; hardness, 3-4), zirconium oxide (ZrO_2 ; hardness, 8-9), silicon oxide (SiO_2 ; hardness, 7-8), etc. The abrasive-grain mixture may have such a volume ratio that the proportion of the hard abrasive grains is 60-90% and that of the soft abrasive grains is

10-40%. A more suitable volume ratio in the mixture is that the proportion of the hard abrasive grains is 70-80% and that of the soft abrasive grains is 20-30%.

[0037] The binder 10 to be used for the stone 10 of the invention is a binder regulated so as to have a softening temperature not higher than a given value, so that the soft abrasive grains, which have chemical reactivity, are not chemically or thermally altered. It is preferable that the binder should be configured of 80-95% by weight low-melting inorganic glass and 5-20% by weight high-melting inorganic mineral.

[0038] The stone 10 may be produced by evenly mixing the abrasive grains, the binder, and ingredients including a pore-forming agent and other aids and then subjecting the mixture to powder regulation, molding, drying, and burning. The burning temperature for stone formation may be 750°C.

(2) Finishing Properties of Soft Abrasive Grains

a) Mechanochemical Function

[0039] It is known that in the case where a stone obtained by fixing soft abrasive grains of CeO_2 or BaSO_4 alone with a vitrified bond is used to superfinish bearing steels (SUJ-2 and HRC60), the stone forms an oxide film (Fe_2O_3 , Fe_3O_4) on the steel surfaces through a solid-phase reaction. This superfinishing is accomplished by a mechanism in which the CeO_2 or BaSO_4 abrasive grains which have been activated by the heat energy due to the finishing friction oxidize steel-surface projections and the oxidized projections are removed with the bond matrix containing the soft abrasive grains.

b) Conformability

(b1) Kinds of Test Stones

[0040] In order to examine the conformability of stones containing soft abrasive grains as the only abrasive grains, vitrified-bond stones were produced. The soft abrasive grains are (A) BaSO_4 (average particle diameter, 6.0 μm), (B) CeO_2 (average particle diameter, 1.4 μm), (C) ZrO_2 (average particle diameter, 1.0 μm), and (D) SiO_2 (average particle diameter, 5.0 μm). The superabrasive (hard abrasive) grains used as comparative abrasive grains are (E) CBN (average particle diameter, 3.0 μm).

[0041] Details of the grainstones are as follows. The same vitrified bond is used, and the binder amount is constant at 0.35 parts by weight per unit abrasive-grain amount. Furthermore, the molding conditions and the burning conditions also are the same. In Table 1 are shown the RH hardness values of the various stones. The RH hardness is determined by the Rockwell test method using scale H in accordance with JIS R6240. Minus (-) values of the hardness indicate the case where the stone is soft and the longer indicator passes by the set point 30 and by 0 and then stops.

[0042] Superfinishing is given to raceway grooves of ball bearings, and the conditions are the same in all the stones. The machining oil is a water-insoluble oil based on a sulfurized fatty oil. In preparation for use, the working surface of each stone is shaped into a protrudent circular-arc surface having a radius corresponding to the circular-arc cross-sectional shape of the inner surface of the groove. In each stone, the pores have been filled with a high-melting wax.

(b2) Number of Works for Conforming

[0043] The results are shown in Table 1.

[Table 1]

Kind of abrasive grains	RH hardness	Number of works for conforming	Stone wear amount ($\mu\text{m}/\text{work}$)
Soft abrasive grains (A) to (D)	-20 to -70	15-20	0.40-0.70
CBN abrasive grains (E)	15-25	20-25	1.1-1.2

[0044] The numbers of works required for conforming the soft-abrasive-grain stones do not differ much from that for the CBN (hard-abrasive-grain) stone although smaller than that. It is rather noted that although the soft-abrasive-grain stones have minus (-) values of RH hardness and are exceedingly soft as compared with the CBN stone, there is little difference therebetween in the number of works for conforming. Furthermore, the average stone wear amount is as small as about 1/2 that of the CBN stone. Namely, the stone layer constituted of soft abrasive grains forms a substance layer which has a soft and weak stone friction surface but is less apt to shed or wear, i.e., a clean layer, thereby bringing about a reduction in stone wear.

(b3) Clean Working Surfaces of Stones

[0045] Figs. 6A to 6E are views which show photographs of the working surfaces of the test stones; Fig. 6A shows the case of the BaSO_4 abrasive grains (A), Fig. 6B shows the case of the CeO_2 abrasive grains (B), Fig. 6C shows the case of the ZrO_2 abrasive grains (C), Fig. 6D shows the case of the SiO_2 abrasive grains (D), and Fig. 6E shows the case of the CBN abrasive grains (E).

[0046] In the CBN-abrasive-grain stone (E), white bright areas due to the fusion bonding of chips are observed (Fig. 6E). In contrast, such areas are not observed in the soft-abrasive-grain stones (A) to (D) (Figs. 6A to 6D). However, the stone working surfaces have a difference in color density due to a difference in stone structure resulting from a difference in abrasive-grain diameter or due to a difference in mechanochemical function, etc. By dispersedly disposing soft abrasive grains in a composite-superabrasive-grain vitrified-bond stone, the working surface of the stone is rendered soft and weak and the conformability to works is improved. However, the conformability is not owing to stone wear. The soft abrasive grains, which do not have an abrading action, mitigate stone clogging or dulling without being directly affected by bond erosion due to chips, thereby serving as a lubricating surface layer to bring about a reduction in stone wear.

(3) Critical Stone Pressure

[0047] In superfinishing, as the pressure increases beyond a certain value, the stone wear amount increases rapidly, resulting in an enhanced abrading action and enhanced roughness of the finished surface. This pressure value is referred to as critical stone pressure (hereinafter expressed by P_c). The vitrified stone, which includes the composite abrasive grains selected in accordance with the invention, has a higher P_c than conventional stones which contain no soft abrasive grains. This is because the soft abrasive grains do not readily shed or wear upon an increase in the pressure applied to the stone surface and do serve as a lubricating surface layer to contribute to a decrease in stone wear. Namely, it can be seen that the soft abrasive grains form a layer of a substance which has a soft and weak stone friction surface but is less apt to shed or wear, i.e., a layer of a lubricating substance.

Examples

[0048] The conformability and other properties of stones having the shape and composition described above, the conformability being a feature of the invention, are explained below by reference to Examples and Comparative Examples.

<Production of Stones>

(a) Kinds of Stones

[0049] In Table 2 are shown the structures of the stones according to Examples and Comparative Examples. The hard abrasive grains in sections 1 to 9 are cubic boron nitride (CBN), while the soft abrasive grains in sections 1 to 3, 6, and 7 are cerium oxide (CeO_2).

[0050] With respect to grain particle diameter (μm), the particle diameter of the CBN in sections 1 to 5 is 4-8 μm (2,500 mesh), and that of the CBN in sections 6 to 9 is 2-4 μm (4,000 mesh). The materials in section 1 and section 3 are of the same quality.

[0051] The binder for each stone is a vitrified bond based on $\text{R}_2\text{O}-\text{RO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{B}_2\text{O}_3$.

[0052] Abrasive grains, the binder, a pore-forming agent, and other aids were evenly mixed as compounding ingredients, and the resultant mixture was subjected to powder regulation, molding, drying, and then burning. The burning temperature for stone formation was 750°C in terms of maximum temperature in sections 1 to 3, 6, and 7, and was 800°C in terms of maximum temperature in sections 4, 5, 8, and 9. Each dried compact was held at that temperature for 3 hours, cooled, and then taken out. The test stones were finished to a given dimensional accuracy, and the pores of the stones were thereafter filled with an organic treating agent.

(b) Stone Hardness, Structure, and Critical Stone Pressure

[0053] In Table 2 are shown the hardness of each stone and the critical stone pressure P_c , besides the composition. The stone hardness was determined by the Rockwell test method using scale H (JIS R6240, Method for Testing Stones) (hereinafter referred to as RH hardness).

[0054] In both the Examples and the Comparative Examples, tests were conducted for the purpose of examining differences in the number of works for conforming among as various RH hardnesses as possible, while taking care so that the RH hardnesses did not localize on the soft side or the hard side.

[0055] Meanwhile, the stones were examined also for wear property, which relates to the number of works for con-

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forming, and for the volume ratio (%) of stone constituent elements (content of hard abrasive grains, Vg1; content of soft abrasive grains, Vg2; porosity Vp; and binder content Vb) and critical stone pressure Pc (MPa), which both may affect finishing performance.

[Table 2]

Section		RH hardness	Volume ratio (%)				Stone critical pressure Pc (MPa)
			Vg1	Vg2	Vp	Vb	
Example	1	32	18.8	4.4	49.7	27.1	3.48
	2	-28	18.2	4.3	52.6	24.9	3.22
Comparative Example	3	32	18.8	4.4	49.7	27.1	3.48
	4	31	21.7	-	50.3	28.0	3.19
	5	-25	21.1	-	52.6	26.3	3.15
Example	6	16	17.3	4.1	51.8	26.8	3.65
	7	-15	17.1	4.0	52.1	26.8	3.61
Comparative Example	8	15	20.5	-	50.7	28.8	3.51
	9	-14	21.6	-	52.0	26.4	3.23
* Vg1: content of hard abrasive grains Vg2: content of soft abrasive grains							

(c) Stone Shape Dimensions

[0056] With respect to the dimensions of each test stone, the stone has a rectangular stick shape having a stone straddle width of 5.5 mm and a thickness of 5.5 mm. A first inclined surface and a second inclined surface which each had a protrudent circular-arc shape with a radius of 3.5 mm that corresponded to the recessed circular-arc cross-section of the raceway groove of an outer ring were formed in the working surface of each stone so that the working surface, when viewed from the direction of the rotation axis of the outer ring as a work to be machined, inclined from the central portion thereof toward both side surfaces of the stone so as to form the shape of the letter V having an angle within the given range. Namely, the same shape as in the embodiment described above, which is shown in Fig. 1, was imparted (hereinafter this shape is often referred to as "two-direction R-curved-surface shape").

<Conforming Test 1>

[0057] Using the stones of the Examples and Comparative Examples classified as sections 1 to 9, the number of works required for conforming each stone to the shape of the outer-ring raceway groove of the outer ring was determined while changing the inclination angle of the first and second inclined surfaces.

(i) Conditions for Conforming

[0058] The outer-ring raceway groove had a groove bottom diameter of 35.75 mm.

[0059] The conditions for conforming, which were common between the Examples and the Comparative Examples, included: a surface roughness resulting from pre-processing grinding of 0.25-0.30 μm Ra (center-line average roughness); a groove-bottom surface velocity of 5 m/s; a stone pivoting frequency of 13.3 Hz; a conforming period of 4 seconds; and a water-insoluble oil based on sulfurized fatty oil was used as a machining oil.

[0060] Completion of the conforming of a stone working surface is determined in such a manner that the stone working surface is colored with an oil-based paint and the time when the coloration has disappeared is used as an index to the completion. The conforming pressure was set at 3.0 MPa, which was not higher than the critical stone pressures shown in Table 2. The number of specimens for each stone is 3-4.

(ii) Results

[0061] As shown in Table 3, the inclination angle in the Example classified as section 1 was changed in the range of 3°-5°. As a result, the number of works for conforming was as small as 1-3. Meanwhile, in the Comparative Example

classified as section 3, which was equal in quality to the Example classified as section 1, the inclination angle was further reduced to 2° and further increased to 6° and to 8° and the effects thereof were examined. As a result, in the case where the inclination angle was as small as 2°, the state of that surface of the stone which was in contact with the work being machined was the same as that of ordinary stones. Namely, the effect of the stone working surface of the Example wherein that portion of the stone working surface which comes into strong contact with the surface being machined has enhanced conformability was not produced. In the case where the inclination angle was increased beyond 5°, the maximum conforming amount increased and it was necessary that a large number of works for conforming be used for imparting a circular-arc shape conforming to the raceway groove of the outer ring.

[0062] It was thus demonstrated that by using an inclination angle of 3-5°, the number of works for conforming can be reduced. It was also seen from those results that the inclination angle is preferably 4°.

[0063] In each of the Examples classified as sections 2, 6, and 7 and the Comparative Examples classified as sections 4, 5, 8, and 9, the number of works for conforming was determined with respect to the inclination angle of 4°. The results given in Table 3 show that the Examples classified as sections 2, 6, and 7 were clearly smaller in the number of works for conforming than the Comparative Examples classified as sections 4, 5, 8, and 9. This is due to the conformability brought about by the composite superabrasive grains including soft abrasive grains and hard abrasive grains.

[Table 3]

Section		Inclination angle (°)	Number of works for conforming
Example	1	3	1-3
		4	1-2
		5	1-2
	2	4	1-2
Comparative Example	3	2	2-5
		6	3-5
		8	4-7
	4	4	4-6
	5	4	3-6
Example	6	4	1-3
	7	4	1-2
Comparative Example	8	4	3-5
	9	4	2-4

<Conforming Test 2>

[0064] This test relates to the number of works for conforming with respect to the shape of the stone working surface.

(i) Production of Stones (grinding shape dimensions)

[0065] The stone working surface of each of stones having a rectangular stick shape which were classified as sections 1, 4, 7, and 9 was shaped into a protrudent circular-arc surface with a radius of 3.5 mm that corresponded to the circular arc of the outer-ring raceway groove of an outer ring. Namely, the same shape as conventional one, which is shown in Fig. 7, was imparted (hereinafter, this shape is often referred to as "one-direction R-curved-surface shape").

[0066] The conditions for conforming are the same as in <Conforming Test 1> above.

(ii) Results

[0067] From the results given in Table 4 concerning the number of works for conforming, it can be seen that the number of works for conforming in the case where the stone working surface has been made to have the two-direction R-curved-surface shape according to the invention is about 1/5 or less the number of works for conforming in the case of the conventional one-direction R-curved-surface shape. That surface shape according to the invention made it possible to reduce the number of works for conforming to 1, which is the minimum number.

[0068] It was further understood that sections 1 and 7, as which composite-superabrasive-grain stones including both soft abrasive grains and hard abrasive grains were classified, were clearly smaller in the number of works for conforming than sections 4 and 9, in which the abrasive grains consisted only of hard abrasive grains.

[Table 4]

Section		Inclination angle (°)	Number of works for conforming
Comparative Example	1	-	16
	7	-	20
Comparative Example	4	-	22
	9	-	27

<Conforming Test 3>

[0069] This test relates to the setting of stone pressure in a conforming operation according to the invention. Namely, the stone pressure was set at values lower than the critical stone pressure or set at a value higher than the critical stone pressure, and the resultant changes in the number of works for conforming were determined. Furthermore, the stone working surfaces obtained by the conforming operations were used to ascertain the finishing performance thereof.

(i) Kinds of Stones

[0070] The Example classified as section 7, which was stably small in the number of works for conforming in <Conforming Test 1>, and the Comparative Example classified as section 9 were used as specimens. The stone shape in either case was the two-direction R-curved-surface shape having an inclination angle of 4°.

(ii) Conditions for Conforming

[0071] Use was made of three conforming pressures, i.e., 0.8 times, 0.9 times, and 1.05 times the critical stone pressure P_c (MPa) shown in Table 2. The other conditions were the same as in <Conforming Test 1>.

(iii) Conditions for Superfinishing

[0072] The outer-ring raceway groove of the outer ring of a ball bearing was superfinished. The surface velocity of the work to be machined is 5 m/sec in both rough machining and finishing. The stone rocking frequencies are 13.3 Hz for rough machining and 2.0 Hz for finishing. The processing periods are 8 seconds for rough machining and 2 seconds for finishing. With respect to each stone, ten works were processed and average values were determined therefrom. The stone surface pressure for both rough machining and finishing is set at a value lower than the conforming pressures, that is, set at 2.5 MPa, which is less than 0.8 P_c .

(iv) Results

(a) Number of Works for Conforming

[0073] As shown in Table 5, at conforming pressures in the range of 0.8-1.05 P_c , the number of works for conforming in the Examples was 1-2 and was stably small as compared with the Comparative Examples. In the Comparative Examples, there was a tendency that the number of works for conforming decreased as the conforming pressure increased.

(b) Finishing Performance

[0074] With respect to the finishing performance evaluated using the stone working surfaces obtained by the conforming operations, the Examples are highly abrasive, show a smaller stone wear amount, and attained a lower surface roughness than the Comparative Examples. Consequently, the Examples had a large value of finishing ratio and were clearly high-performance stones.

[0075] It is apparent that not only the difference in stone superfinishing performance but also the difference in the number of works for conforming are due to the feature of the composite-superabrasive-grain vitrified stones according

to the invention.

(c) Conclusion

[0076] In case where the conforming pressure exceeds the critical stone pressure (P_c), the stone wear amount (W) increases and a deterioration in finished surface (R_a) or a decrease in finishing ratio (T/W) results, although the number of works for conforming (N) decreases. Conversely, in case where the conforming pressure is not higher than the critical stone pressure (P_c), the number of works for conforming (N) increases and the stock removal (T) decreases although the surface roughness is low due to a decrease in grinding wear amount (W).

[0077] Consequently, a preferred conforming pressure is in the range of $0.8P_c$ to $1.0P_c$. However, since conforming pressures around $1.0P_c$ result in large fluctuations in finishing performance, it is more preferable that the conforming pressure should be $0.85P_c$ to $0.95P_c$ ($90 \pm 5\%$).

[Table 5]

		Example	Comparative Example	Example	Comparative Example	Example	Comparative Example
Section		7	9	7	9	7	9
Number of works for conforming		0.8 P_c		0.9 P_c		1.05 P_c	
	N (number of works)	1-2	3-5	1-2	2-4	1-2	2-3
Removal amount	T ($\mu\text{m}/\text{work}$)	8.9	8.2	9.2	8.6	11.6	10.0
Stone wear amount	W ($\mu\text{m}/\text{work}$)	0.57	0.90	0.58	0.95	0.75	1.14
Surface roughness	R_a (μm)	0.021	0.025	0.026	0.029	0.033	0.034
Finishing ratio	T/W	15.6	9.1	15.9	9.1	15.5	8.8

[0078] As explained above, according to the superfinishing stone of the invention, since the shape of the stone working surface in the tip part is configured of a first inclined surface and a second inclined surface which meet each other approximately in the shape of the letter V, the portion which comes into strong contact with the surface to be machined has an increased contact area, while the portion which comes into weak contact therewith has a reduced contact area. As a result, the stone working surface comes to undergo an overall hit and have improved conformability with a minimum number of works required for conforming. Furthermore, by dispersedly disposing soft abrasive grains, a lubricant layer which is non-abrasive, soft, and weak but is less apt to shed is formed, resulting in a further improvement in conformability and a reduction in stone wear amount. Thus, the inconsistent stone requirements, i.e., stone quality that brings about improved conformability and finishing performance, can be simultaneously satisfied.

[0079] Moreover, the superfinishing stone of the invention is reduced in stone wear amount and can be prevented from having a shortened life due to stone shape deformation. Desired surface accuracy can hence be obtained therewith. Consequently, although the superfinishing of the raceway grooves of outer rings has limitations on stone length (stone use amount) and hence has had problems in that the stone life is short and the frequency of stone replacement is high, it is possible to prolong the stone life by using the vitrified-bond stone in which superhard cubic boron nitride (CBN) abrasive grains or diamond (SD) abrasive grains are used. Furthermore, even in the case of using the vitrified-bond stone in which superhard cubic boron nitride (CBN) abrasive grains or diamond (SD) abrasive grains are used, not only the conformability thereof can be improved but also a reduction in stone wear amount can be attained, rendering a further prolongation of the life possible.

[0080] The present invention should not be construed as being limited to the embodiments described above, and modifications, improvements, and the like can be suitably made therein.

[0081] In the embodiments described above, details of the superfinishing stone and superfinishing methods using the stone were explained with respect to use thereof as superfinishing stones suitable for the outer-ring raceway groove of a ball bearing equipped with an inner ring, an outer ring, and a plurality of balls freely rollably disposed between the inner and outer rings. However, the superfinishing stone of the invention can be applied not only to outer-ring raceway grooves but also to inner-ring raceway grooves and other works to be machined.

[0082] Furthermore, the hard abrasive grains are not limited to cubic boron nitride (CBN) and diamond (SD), and use may be made of other hard abrasive grains such as white aluminum oxide (WA) or silicon carbide (GC) abrasive grains. Especially for the superfinishing of the raceway groove of an inner ring, which has no limitation on stone length (stone use amount), abrasive grains of white aluminum oxide (WA) and silicon carbide (GC) may be used.

[0083] This application is based on a Japanese patent application filed on June 21, 2012 (Application No. 2012-139976), the contents thereof being incorporated herein by reference.

DESCRIPTION OF REFERENCE NUMERALS AND SIGNS

[0084]

- 2 Outer ring
- 3 Outer-ring raceway groove
- 10 Superfinishing stone
- 11 Tip part
- 12a First inclined surface
- 12b Second inclined surface
- α Inclination angle
- B Straddle width (second-direction length)
- d Maximum conforming amount

Claims

1. A superfinishing stone **characterized by** being equipped at a tip part thereof with a first inclined surface and a second inclined surface which, when viewed from a first direction, extend from a central portion respectively toward both sides at an inclination angle of 3°-5° with a second direction that is perpendicular to the first direction and meet each other approximately in the shape of the letter V, the first inclined surface and the second inclined surface each having the shape of a circular arc when viewed from the second direction, and by having been obtained by binding composite abrasive grains with a vitrified bond, the composite abrasive grains comprising soft abrasive grains which have chemical reactivity with a material to be machined but do not have abrasive properties thereagainst and hard abrasive grains which have abrasive properties against the material to be machined.
2. The superfinishing stone according to claim 1, **characterized in that** when the second-direction length which is the length along the second direction is expressed by B (mm) and the inclination angle of the first inclined surface and the second inclined surface is expressed by α (°), then the maximum conforming amount d represented by the following equation (I) is 0.13-0.22 mm.
$$d=(B/2)\times\tan\alpha \quad (I)$$
3. The superfinishing stone according to claim 1 or 2, **characterized in that** the composite abrasive grains include 10-40% the soft abrasive grains and 60-90% the hard abrasive grains, in terms of volume ratio in the mixture.
4. The superfinishing stone according to any one of claims 1 to 3, **characterized in that** the hard abrasive grains are hard abrasive grains of at least one kind selected from abrasive grains of cubic boron nitride and abrasive grains of diamond and the soft abrasive grains are soft abrasive grains of one or more kinds selected from cerium oxide, barium sulfate, silicon oxide, and zirconium oxide.
5. A superfinishing method which comprises superfinishing the outer-ring raceway groove of the outer ring of a ball bearing using the superfinishing stone according to any one of claims 1 to 4, **characterized in that** the superfinishing stone is disposed so that the first direction is parallel with the direction of the rotation axis of the outer ring and the second direction coincides with the circumferential direction of the outer ring and an operation for conforming the superfinishing stone is performed before the superfinishing operation at a pressure

which is $90 \pm 5\%$ of the critical stone pressure.

- 5
6. The superfinishing method according to claim 5, **characterized in that** the superfinishing operation is conducted at a stone surface pressure which is lower than the pressure used in the conforming operation.
- 10
7. A ball bearing equipped with an inner ring, an outer ring, and a plurality of balls disposed between the inner ring and the outer ring in a freely rollable manner, **characterized in that** the outer-ring raceway groove of the outer ring has been superfinished by the superfinishing method according to claim 5 or 6.
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55

FIG. 1

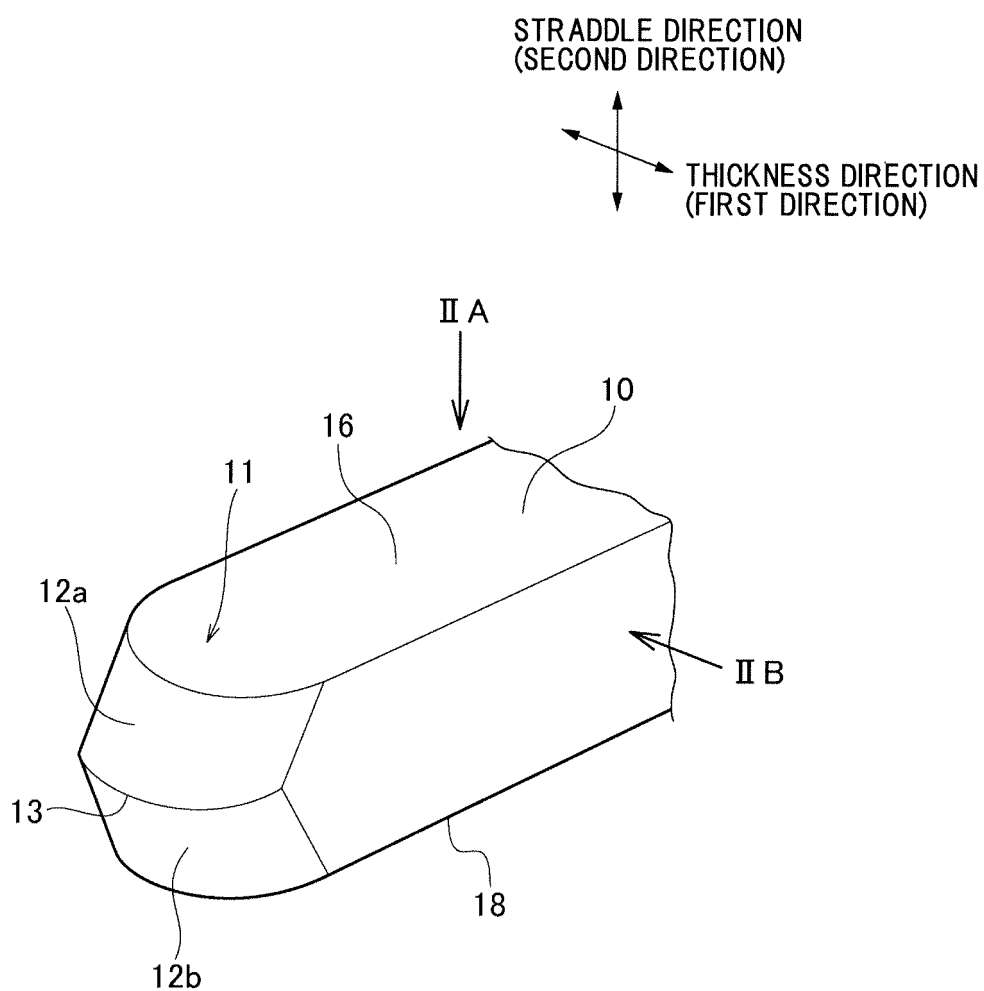


FIG. 2A

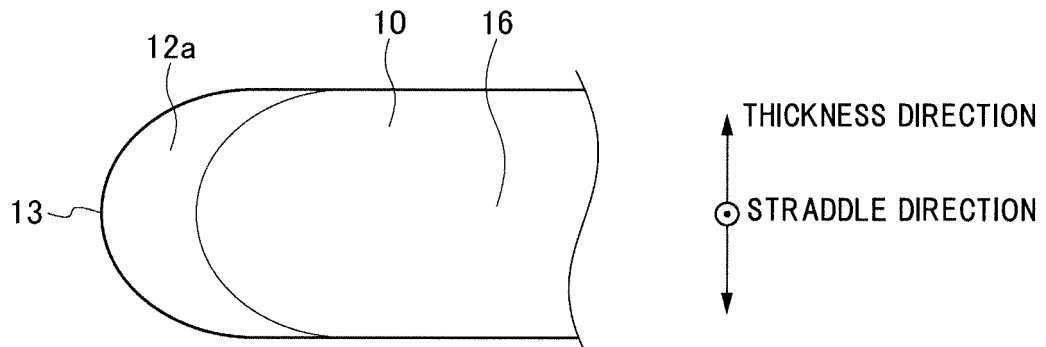


FIG. 2B

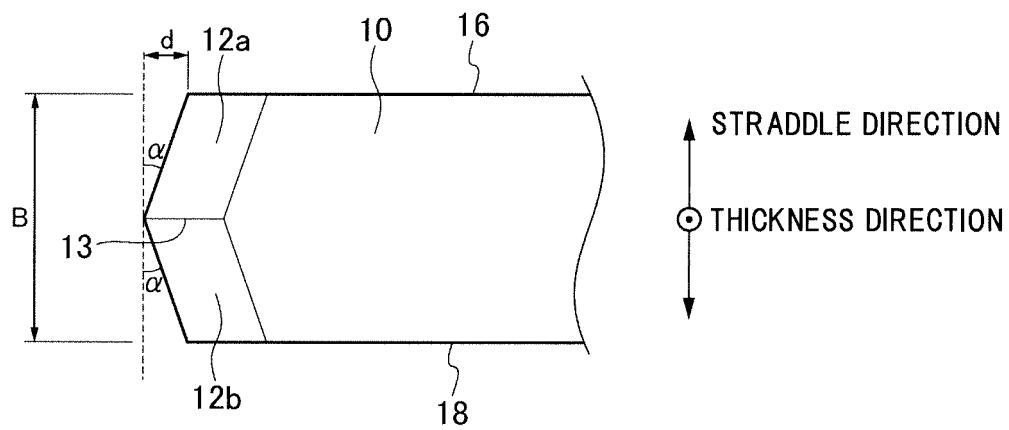


FIG. 3

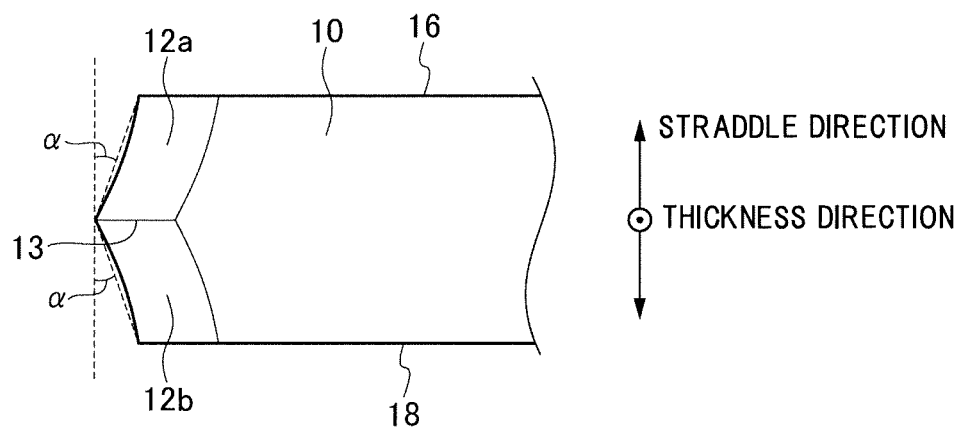


FIG. 4A

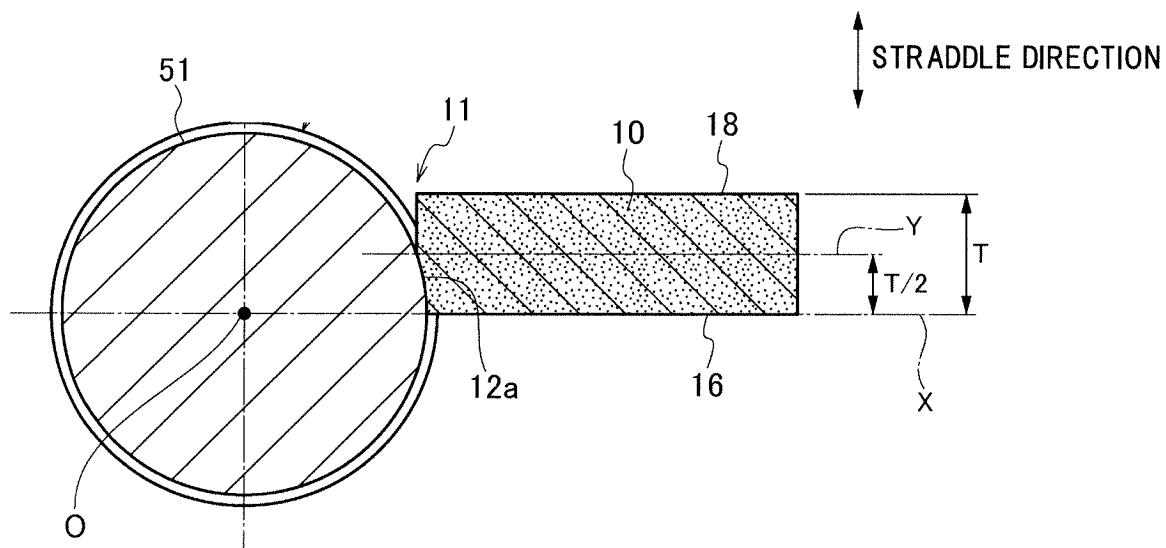


FIG. 4B

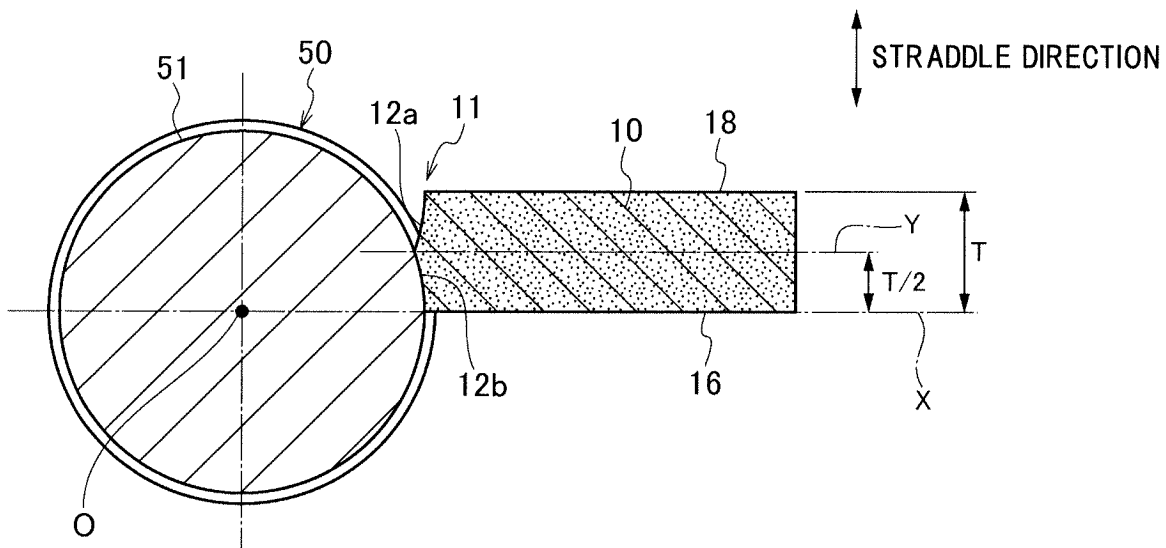


FIG. 5

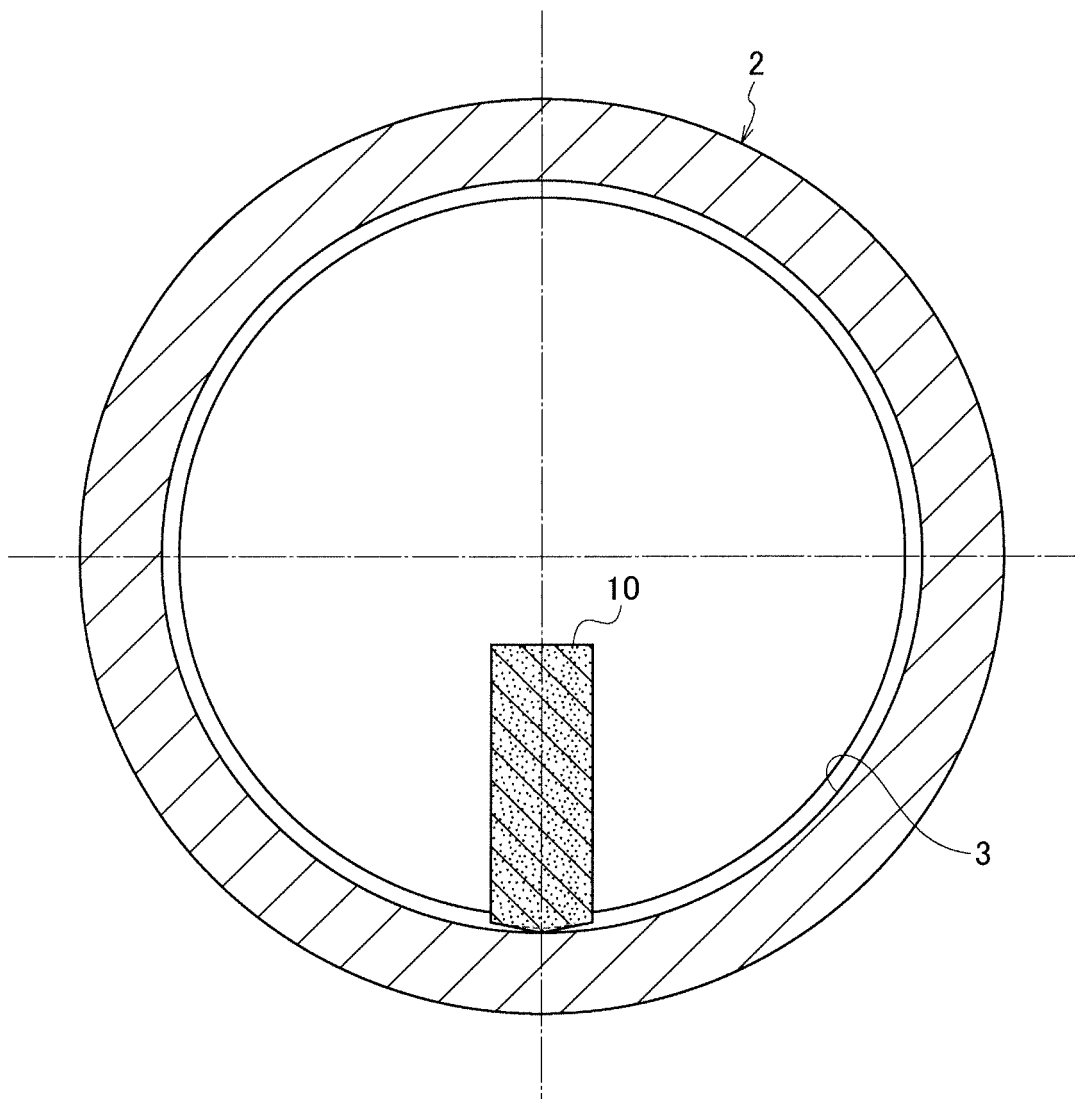


FIG. 6A

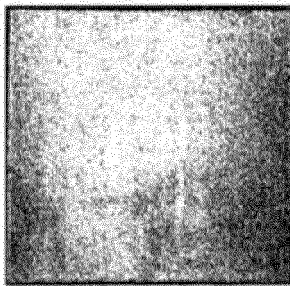


FIG. 6B



FIG. 6C

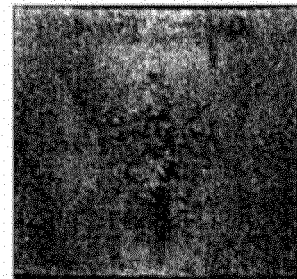


FIG. 6D

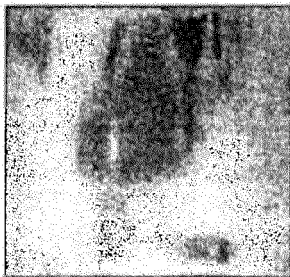


FIG. 6E

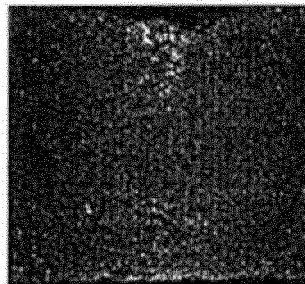


FIG. 7

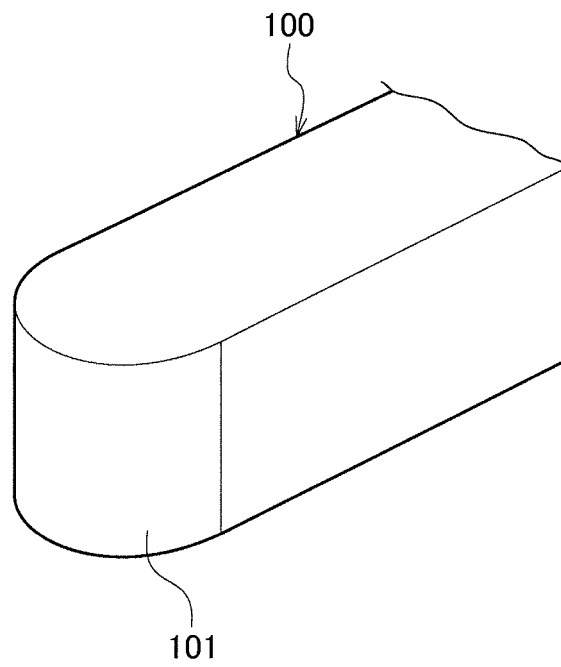


FIG. 8

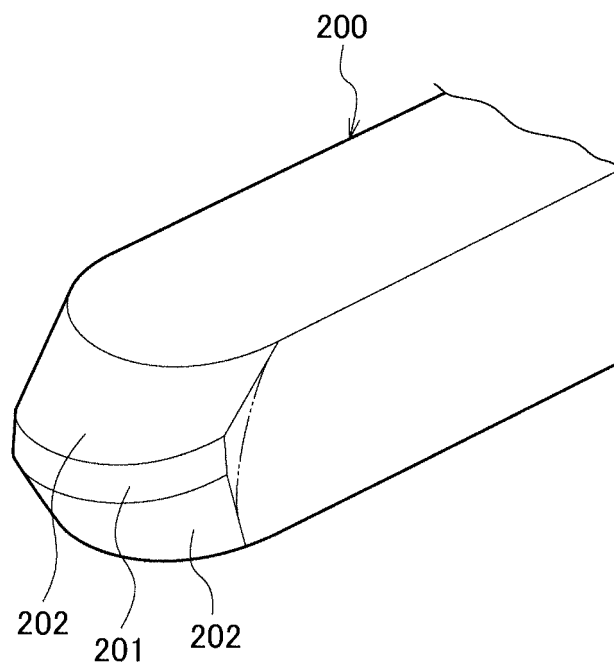


FIG. 9A

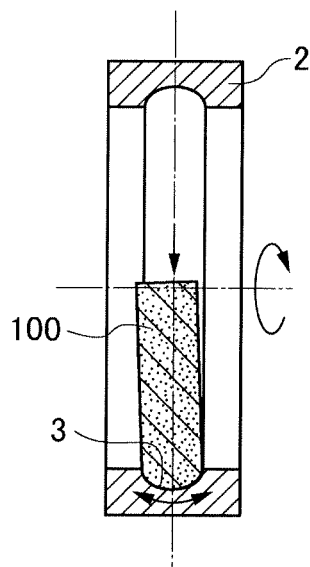


FIG. 9B

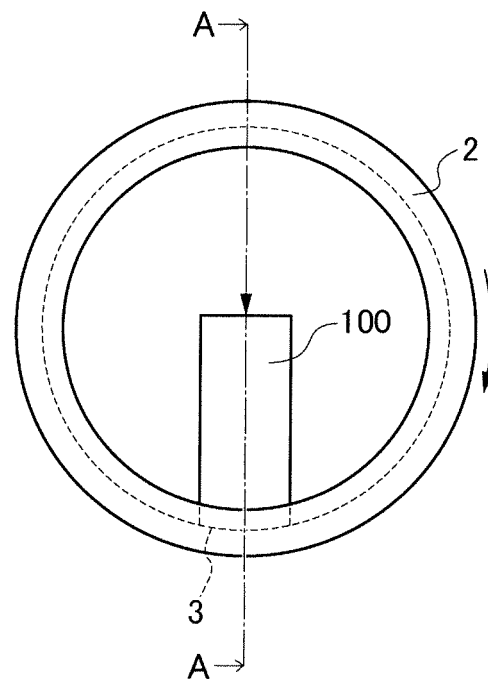
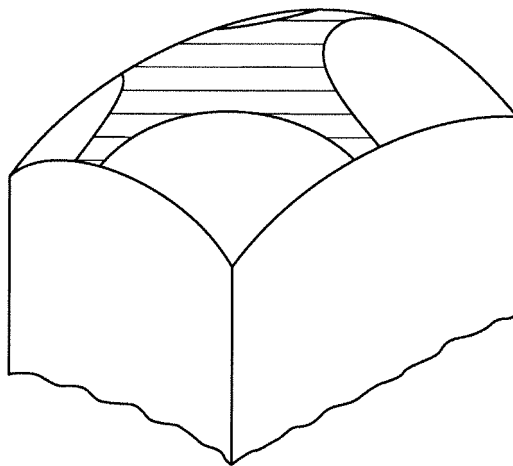


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/071888

A. CLASSIFICATION OF SUBJECT MATTER

B24D3/00(2006.01) i, B24B19/06(2006.01) i

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)

B24D3/00, B24B19/06

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2012

Kokai Jitsuyo Shinan Koho 1971-2012 Toroku Jitsuyo Shinan Koho 1994-2012

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 A	JP 2600506 Y2 (NTN Corp.), 12 October 1999 (12.10.1999), paragraphs [0001], [0009] to [0017]; all drawings (Family: none)	1-4 5-7
Y A	JP 2006-130635 A (Mizuho Co., Ltd.), 25 May 2006 (25.05.2006), claims; paragraphs [0015] to [0018], [0039] to [0043], [0085] (Family: none)	1-4 5-7
A	JP 2004-261904 A (NSK Ltd.), 24 September 2004 (24.09.2004), entire text; all drawings (Family: none)	1-7

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

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"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
27 September, 2012 (27.09.12)Date of mailing of the international search report
09 October, 2012 (09.10.12)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

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- JP 2012139976 A [0083]