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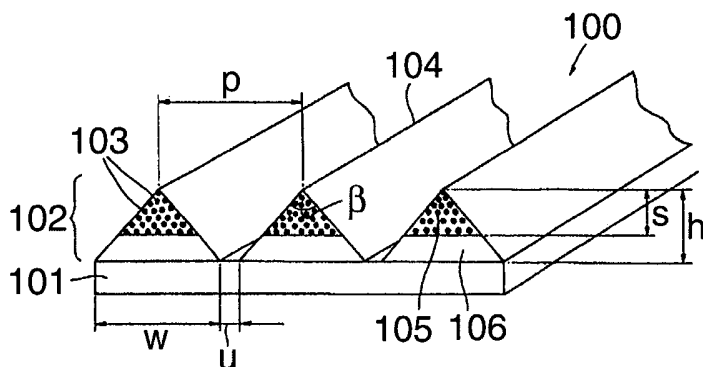
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(54) Title: ABRADING METHOD OF CURVILINEAR SURFACE OF WORKPIECE



(57) Abstract: An abrading method which
is excellent in loading resistance and durabil-
ity, and allows a minute finishing to be pro-
vided in a short period in the case of abrading
a curvilinear surface of a workpiece.

ABRADING METHOD OF CURVILINEAR SURFACE OF WORKPIECE

Field of the Invention

5 The present invention relates to an abrading method of curvilinear surface of workpiece, in particular to an abrading method of an outer peripheral surface of a cylindrical workpiece.

Background of the Invention

10 Curvilinear surfaces such as convex surface, concave surface and spherical surface of a workpiece, and peripheral surfaces of a cylinder or a narrowed cylinder, are abraded by contacting the curvilinear surface of the workpiece with a sheet-like abrasive article, and moving the workpiece relative to the abrasive article. The workpiece herein described include, for example, parts composed of hard materials such as glass, ceramic, and metal. For example, an outer peripheral surface of a cylindrical workpiece is able to be abraded
15 in such a manner that a sheet-like abrasive material is pressed on the outer peripheral surface of the cylindrical workpiece to be rotated while supplying a cutting fluid so as to gradually feed the abrasive material. In the case of performing a precise surface finishing, such an abrading method is performed, for example, by using a superfinishing device (Model; GEM04150P, manufactured by GEM Company, Youngstown OH, USA) or a
20 microfinisher device (Model; GBQ740/1500/1800, manufactured by Fujikoshi K.K., Fujikoshi-honmachi, Toyama, Japan) while desirably performing oscillation in a lateral direction.

In order to minutely finish a surface of a workpiece, a constant surface roughness needs to be repeatedly produced. A precise abrading is a work such that a locally deep
25 scratch is replaced with a shallow uniform scratch by abrading. Recently, for example, a particularly minute finishing level of R_a of 0.05 μm or less has been required for an outer peripheral surface of cylindrical parts for a crankshaft and a camshaft of an engine.

On the occasion of performing a precise abrading, an abrasive tape has been generally used as an abrasive material, which is manufactured by applying the electrostatic
30 coating of abrasive particles to the surface of a film substrate, or applying and drying slurry containing abrasive particles and a resin binder to the surface of a film substrate. An abrasive surface, however, is merely coated with minute abrasive particles and thereby

has an irregular microstructure. Thus, particularly, in the case of abrading metal and the like therewith, loading is easily caused and abrasive power is easily deteriorated. In order to effectively abrade, therefore, it is requested to increase the feed speed of an abrasive tape and constantly abrade by an abrasive surface with no loading, thereby requiring a large quantity of abrasive materials and taking a long time to finish to a minute abraded surface.

Japanese Patent Kokai Publication No. S62(1987)-255069 describes an abrasive tape having an abrasive layer on one surface of a substrate, in which a multitude of regular hexagons are evenly arranged on the whole surface of the abrasive layer and concave portions are formed in the periphery and the center of the regular hexagons.

Japanese Patent Kokai Publication No. 2001-179640 describes an abrasive material having a substrate and an abrasive layer provided on the substrate, in which the abrasive layer has a plurality of regularly arranged ridges having a definite shape. The literature describes a method of using the material in relation to an optical abrasive disc.

Japanese Patent Kokai Publication No. H9(1997)-225510 describes a method of abrading an outer peripheral surface of a cylindrical workpiece such that a plurality of abrading steps by lapping films with different roughness are performed while using lapping films with finer roughness toward the final abrading step in order to shorten abrading time.

Summary of the Invention

The present invention has been made to solve the above-mentioned conventional problem and an object thereof is to provide an abrading method which is excellent in loading resistance and durability, and allows a minute finishing to be provided in a short period in the case of abrading a curvilinear surface of a workpiece.

The present invention provides a method of abrading a curvilinear surface of workpiece comprising:

providing an abrasive article comprising a backing and an abrasive layer placed on the backing, said backing having a major surface, a longitudinal direction, and opposing side edges, each side edge being substantially parallel to said longitudinal direction, said abrasive layer comprising a first layer adhered to said major surface and a second layer comprising abrasive particles dispersed within a binder, said abrasive layer comprising a

plurality of parallel rows having a prismatic or a truncated prismatic shape, said parallel rows being aligned at an angle between 10 and 80 degrees with respect to said longitudinal direction;

contacting said curvilinear surface of said workpiece with said abrasive article; and

5 moving said workpiece relative to said abrasive article to at least partially abrade said curvilinear surface;

whereby achieving the above-mentioned object.

10 An abrasive material employed in the present invention has parallel rows of plural ridges. The rows of ridges are at an angle with a longitudinal direction of the abrasive material. Also, a shape of the top of ridges is a plane or a line parallel with the surface of a substrate, so that abrasive particles are uniformly applied to a surface to be abraded and thereby finishing is rendered extremely uniform and precise.

Brief Description of the Drawings

15 Fig. 1 is a cross-sectional perspective view of an abrasive material as an embodiment of the present invention, in which an abrasive layer has a ridge-like structure.

Fig. 2 is a top view showing a ridge-like structure of a house shape having slopes in four directions.

20 Fig. 3 is a top view schematically showing an example of the arrangement of a ridge-like structure.

Figs. 4a and 4b top views are schematically showing examples of exemplary arrangements of ridge-like structures.

Fig. 5 is a schematic view showing a constitution of a superfinishing device (manufactured by GEM Company).

25 Fig. 6 is a schematic view showing a constitution of a microfinisher device (manufactured by Fujikoshi K.K.).

Fig. 7 is a cross-sectional view of an abrasive layer of Example 1, which was cut by a plane vertical with a longitudinal direction of the ridges.

30 Fig. 8 is a graph showing the results of measuring the change of the surface roughness of a workpiece after being abraded with respect to abrading time by a probe-type surface roughness meter.

Detailed Description

Fig. 1 is a cross-sectional perspective view of an abrasive material as an embodiment of the present invention, in which an abrasive layer has a ridge-like structure. An abrasive material 100 is an abrasive material having a substrate 101 and an abrasive layer 102 provided on the surface of the substrate.

Exemplary materials for a substrate of the present invention include polymer film, paper, cloth, metal film, vulcanized fiber, non-woven substrate, a combination thereof and a processed product thereof. In the case of abrading an outer peripheral surface of a cylindrical workpiece, a substrate is a flexible material. Also, a substrate is transparent with respect to ultraviolet irradiation. The reason therefor is to be convenient in manufacturing processes.

For example, a substrate may be a polymer film such as a polyester film. Also, a polymer film may be undercoated with a material such as polyethylene acrylic acid in order to promote the adhesion of an abrasive layer to a substrate.

The abrasive layer 102 contains a matrix of a binder and abrasive particles 103 dispersed therein. The abrasive layer is formed from slurry containing a plurality of abrasive particles dispersed into the binder in an unhardened or ungelled state. In hardening or gelating, the abrasive layer is solidified, namely, fixed to a predetermined shape and a predetermined structure.

The size of abrasive particles in the abrading for the final finishing is 0.01 to 1 μm , exemplary 0.01 to 0.5 μm and more exemplary 0.01 to 0.1 μm , while 0.5 to 20 μm , exemplary 0.5 to 10 μm in a rough abrading. Examples of abrasive particles suitable for the present invention include diamond, cubic boron nitride, cerium oxide, fused aluminum oxide, heat-treated aluminum oxide, sol-gel aluminum oxide, silicon carbide, chromium oxide, silica, zirconia, alumina zirconia, iron oxide, garnet and a mixture thereof. A particularly exemplary example for a rough abrading is diamond, cubic boron nitride, aluminum oxide and silicon carbide, while silica and aluminum oxide for the finishing abrading.

A binder forms an abrasive layer by hardening or gelating. Examples of a binder for the present invention include phenolic resin, resol-phenol resin, aminoplast resin, urethane resin, epoxy resin, acrylate resin, polyester resin, vinyl resin, melamine resin, acrylated isocyanurate resin, urea-formaldehyde resin, isocyanurate resin, acrylated

urethane resin, acrylated epoxy resin and a mixture thereof. A particularly exemplary example is phenolic resin and polymer resol-phenol resin containing an organic solvent.

A binder may be irradiation-hardening. A irradiation-hardening binder is a binder which is at least partially hardened or at least partially polymerizable by irradiation
5 energy. An energy source such as heat, infrared irradiation, electron beam irradiation, ultraviolet irradiation or visible light irradiation is used depending on a binder to be used.

Typically, these binders are polymerized by a free radical mechanism. These are exemplary selected from the group consisting of acrylated urethane, acrylated epoxy, an aminoplast derivative having an α , β -unsaturated carbonyl group, an ethylenic unsaturated
10 compound, an isocyanurate derivative having at least one acrylate group, isocyanate having at least one acrylate group and a mixture thereof.

In the case where a binder is hardened by ultraviolet irradiation, a photoinitiator is required to start free radical polymerization. Examples of a photoinitiator for this purpose include organic peroxide, an azo compound, quinone, benzophenone, a nitroso compound,
15 an acryl halide, hydrazone, a mercapto compound, a pyrylium compound, triacrylimidazole, bisimidazole, chloroalkyltriazine, benzoin ether, benzyl ketal, thioxanthone and an acetophenone derivative. An exemplary photoinitiator is 2,2-dimethoxy-1,2-diphenyl-1-ethanone.

In the case where a binder is hardened by visible light irradiation, a photoinitiator
20 is required to start free radical polymerization. Examples of a photoinitiator for this purpose are described on line 25 of column 3 to line 10 of column 4, lines 1 to 7 of column 5 and lines 1 to 35 of column 6 in United States Patent Publication No. 4,735,632, which are here referred to.

The weight ratio of abrasive particles to a binder is generally in a range of
25 approximately 1.5 to 10 parts of abrasive particles with respect to one part of a binder, exemplary approximately 2 to 7 parts of abrasive particles with respect to one part of a binder. This ratio varies depending on the size of abrasive particles, the kind of a binder to be used, and the use of an abrasive material.

In the case of smoothly and precisely abrading a hard material such as cylindrical
30 parts for a crankshaft and a camshaft of an engine, the exemplary concentration range of abrasive particles contained in an abrasive layer is as follows: 43 to 90 weight % in the case where abrasive particles are silicon carbide, 70 to 90 weight % in the case where

abrasive particles are spherical abrasive particles such as alumina silica, 37 to 90 weight % in the case where abrasive particles are alumina, and 39 to 90 weight % in the case where abrasive particles are diamond.

5 An abrasive layer may contain a material except abrasive particles and a binder; for example, ordinary additives such as a coupling agent, a wetting agent, a dyestuff, a pigment, a plasticizer, a filler, a stripping agent, an abrasive aid and a mixture thereof.

10 An abrasive layer can contain a coupling agent. The addition of a coupling agent can notably reduce the covering viscosity of slurry used for forming an abrasive layer. Examples of such a coupling agent for the present invention include organic silane, zircoaluminate and titanate. The quantity of a coupling agent is generally less than 5 weight % of a binder, exemplary less than 1 weight % based on a total weight of an abrasive layer.

15 The abrasive layer 102 has a plurality of rows of ridges 104 arranged in parallel. These ridges 104 are a prismatic shape such that a triangle pole is put sideways. The vertex angle β of the ridges 104 is typically 30 to 150 degree, exemplary 45 to 140 degree. A cross section of the ridges cut by a plane vertical with a longitudinal direction thereof may not be an isosceles triangle. In the case where the above-mentioned cross section of the ridges is not an isosceles triangle, the ridges have a steep slope and an easy slope.

20 The tops of the ridges 104 are located on a plane parallel with the surface of a substrate substantially over the whole region of an abrasive material, whereby abrasive particles are uniformly applied to a surface to be abraded and finishing is rendered extremely uniform and precise. In Fig. 1, a symbol h represents the height of the ridges from the surface of a substrate. The symbol h is typically 2 to 600 μm , exemplary 4 to 300 μm . The variation of the height of lines on the tops is 20% or less of the height of the ridges 104, more exemplary 10% or less.

25 The ridges 104 exemplary have a two-layer structure of a first layer 106 made of a binder arranged at foot portion, and a second layer 106 made of a binder containing abrasive particles arranged at top portion. By allowing the ridges 104 to have such a two-layer structure, the quantity of comparatively expensive abrasive particles can be saved, whereby an abrasive material can be provided at a lower cost. Also, a binder in the foot portion 106 can be designed merely in consideration of an adhesive performance to a substrate, thereby leading to less occurrence of poor adhesion to a substrate. In Fig. 1, a

symbol s represents the height of a top portion of the ridges. The symbol s is, for example, 5 to 95% of the height h of the ridges, exemplary 10 to 90%.

In the ridges 104, the second layer 105 performs an abrading function. While the abrasive material is subjected to abrasion, the ridges wear starting from the second layer, thereby allowing unused abrasive grains to appear. Therefore, in order to increase the abrasive property of the abrasive material, the concentration of the abrasive grains in the second layer is exemplary increased to be as high as possible so that the abrasive material may have a higher abrasive property to be suited for abrading a hard material. The concentration of the abrasive grains in the second layer more exemplary not less than 90% of the critical pigment volume concentration (CPVC).

The critical pigment volume concentration (CPVC) as used herein means a pigment volume concentration (PVC) when the gaps among pigment particles are just filled with a binder, in mixing the pigment with the binder. In the case where the binder is liquid, the mixture has fluidity if the concentration is less than the critical pigment volume concentration, whereas the mixture loses its fluidity if the concentration exceeds the critical pigment volume concentration. If the concentration of the abrasive grains in the second layer is less than 90% of the critical pigment volume concentration, the abrasive property of the abrasive material may become insufficient.

The first layer 106, namely the lower portion of the abrasive layer adhering to the substrate, does not usually perform an abrading function. This is because, if the abrasive layer is worn to the lower portion, the abrasive material is usually discarded. The first layer 106 that does not perform the abrading function need not contain abrasive grains, so that the first layer 106 may be made of the binder alone.

By allowing the ridge 104 to have such a two-layer structure, the amount of the comparatively expensive abrasive grains can be saved, whereby the abrasive material can be provided at a lower cost. In addition, since the binder in the first layer 106 can be designed considering only the adhesive power of the binder to the substrate, poor adhesion to the substrate hardly occurs.

The ridges 104 are arranged in a stripe pattern. In Fig. 1, a symbol w represents the length of a short bottom side of the ridges (the width of the ridges). A symbol p represents a distance between the tops of the adjacent ridges, namely, a length equivalent to the pitch of the ridges. A symbol u represents a distance between long bottom sides of

the adjacent ridges. The symbol w is, for example, 2 to 2000 μm , exemplary 4 to 1000 μm . The symbol p is, for example, 2 to 4000 μm , exemplary 4 to 2000 μm . The symbol u is, for example, 0 to 2000 μm , exemplary 0 to 1000 μm .

The length of the ridges 104 may be extended substantially over the whole region of an abrasive material. Alternatively, the ridges may be cut to a proper length. It is exemplary that the basal plane of the ridges 104 has an aspect ratio of 2 or more, exemplary 5 or more. The ends thereof may be aligned or non-aligned. The ends of the prism-shaped ridges may be cut at an acute angle from the bottom thereof to form a house shape having slopes in four directions. Fig. 2 is a top view of the ridges in this embodiment.

In Fig. 2, a symbol l represents the length of a long bottom side of the ridges. A symbol v represents a distance of a portion of the ridges cut at an acute angle. A symbol x represents a distance between short bottom sides of the adjacent ridges. The symbols w , p and u signify the same as in Fig. 4. The symbol l is, for example, 5 to 10000 μm , exemplary 10 to 5000 μm . The symbol v is, for example, 0 to 2000 μm , exemplary 1 to 1000 μm . The symbol x is, for example, 0 to 2000 μm , exemplary 0 to 1000 μm . The symbol w is, for example, 2 to 2000 μm , exemplary 4 to 1000 μm . The symbol p is, for example, 2 to 4000 μm , exemplary 4 to 2000 μm . The symbol u is, for example, 0 to 2000 μm , exemplary 0 to 1000 μm .

Also, in another embodiment, the ridges may be a prismatic trapezoid such that the top is cut by a predetermined height. In that case, it is exemplary that the tops of the ridges compose a plane parallel with the surface of a substrate and this substantially whole plane is located on a plane parallel with the surface of a substrate, whereby abrasive particles are uniformly applied to a surface to be abraded and finishing is rendered extremely uniform and precise. The height of the ridges is 5 to 95%, exemplary 10 to 90% of the height h of the three-dimensional elements before the top is cut.

An abrasive surface of an abrasive material of the present invention has a ridge-like structure, so that the abrasive function is anisotropic and the abrasive performance varies with the direction of moving a surface to be abraded with respect to an abrasive surface. In the case of smoothly and precisely abrading an outer peripheral surface of a cylindrical workpiece, particularly a hard material such as cylindrical parts for a

crankshaft and a camshaft of an engine, a traveling direction of a surface to be abraded is exemplary unvertical with a longitudinal direction of the ridges.

Fig. 3 is a top view schematically showing an example of the arrangement of a ridge-like structure for an abrasive material of the present invention. In Fig. 3, an arrow A represents a direction parallel with a traveling direction of a surface to be abraded in the abrading process. This direction is named a longitudinal direction of an abrasive material. A direction vertical with the longitudinal direction is named a lateral direction of an abrasive material. In the case of abrading a cylindrical workpiece, the lateral direction is rendered parallel with an axis thereof. The ridges 304 of an abrasive material 300 are arranged so that a longitudinal direction thereof forms an angle θ with the longitudinal direction of an abrasive material.

The angle θ is properly adjusted in a range of 5 to 85 degree, exemplary 15 to 80 degree, more exemplary 30 to 70 degree. The angle θ of less than 5 degree makes it difficult to obtain minute finishing, while the angle θ of more than 85 degree easily brings loading.

An arrangement form of the ridges is not limited to a stripe pattern and may be, for example, a pattern of alternate arrangement as shown in Fig. 4a and a pattern of zigzag arrangement as shown in Fig. 4b.

An abrasive material employed in the present invention is exemplary manufactured by a method described in columns 0057 to 0069 of Patent Literature 2.

According to an abrading method of the present invention, an outer peripheral surface of a cylindrical workpiece is exemplary abraded. The abrading is performed; for example, the above-mentioned abrasive material is pressed on an outer peripheral surface of a cylindrical workpiece so that a longitudinal direction thereof is rendered vertical with an axis of the cylindrical workpiece; and then the cylindrical workpiece is rotated while supplying a cutting fluid, including, for example, a lubricant, a coolant, or a combination thereof, and the abrasive material can be gradually fed in the direction reverse or forward to a traveling direction of a surface to be abraded, more briefly with oscillation in a lateral direction. Such an abrading method is typically performed by using a superfinishing device and a microfinisher device.

Fig. 5 is a schematic view showing a constitution of a superfinishing device. An abrasive material 501 is let out from a supply roll 502 and wound to a take-up roll 504

through a contact roll 503. The contact roll is pressed on an outer peripheral surface of a cylindrical workpiece 506 by an air cylinder 505. The abrading is performed by rotating the cylindrical workpiece in the arrow direction while feeding the abrasive material in the direction reverse to a traveling direction of a surface to be abraded.

5 Fig. 6 is a schematic view showing a constitution of a microfinisher device. Continuous abrasive materials 601 and 602 are closely pressed on an outer peripheral surface of a cylindrical workpiece 603 through a stone 604 by a shoe 605. Then, the abrading is performed by rotating the cylindrical workpiece, while predetermined amount of the abrasive material is fed in every completion of the rotation.

10 The present invention is more specifically described by the following embodiments and is not limited thereto. In the embodiments, values denoting the quantity of components signify part by weight unless otherwise specified.

EXAMPLES

15 Examples 1 and 2

A mold sheet made of polypropylene was prepared, which has concaves in the shape of inverted ridges of a prismatic trapezoid having a steep slope and an easy slope. A coating solution of an abrasive material having a composition shown in Table 1 was applied to the mold sheet by a knife coater and dried at a temperature of 50°C for 5
20 minutes. A lamination binder shown in Table 2 was applied thereto, and further a primed polyester film Type HPE having a thickness of 75 μm manufactured by TEIJIN DUPONT FILMS JAPAN LIMITED (Chiyoda-ku, Tokyo, Japan) was superposed thereon and laminated with pressure by a roll. The lamination binder was irradiated with ultraviolet rays from the side of the polyester film so as to be hardened. Next, a binder of the coating
25 solution of an abrasive material was heated at a temperature of 90°C for 20 hours so as to be hardened.

The mold sheet was removed and the resultant was further heated at a temperature of 110°C for 24 hours to be thereafter cooled to room temperature, whereby obtaining an abrasive material. This abrasive material has an abrasive layer in which the ridges in the
30 shape of a prismatic trapezoid were arranged in a stripe pattern. Fig. 7 is a cross-sectional view of this abrasive layer which was cut by a plane vertical with a longitudinal direction of the ridges. Each size is shown in Table 3.

Table 1

	Example 1	Example 2
Kinds of Abrasive Particles	Alumina 20 μ m (BFRPL P800) ^{a)}	Alumina 20 μ m (BFRPL P800) ^{a)}
Abrasive Particles	100.00 parts by weight	100.00 parts by weight
Resolphenol Resin (Nonvolatile Content 60%, Water 20%, Organic Solvent Balance)	58.33 parts by weight	41.67 parts by weight
Propylene Glycol Monomethyl Ether	30.00 parts by weight	35.00 parts by weight
Total	188.33 parts by weight	176.67 parts by weight
Abrasive particles% by weight in abrasive layer	74	80
Abrasive particles% by volume in abrasive layer = A	48	56
Critical pigment volume concentration of Abrasive Particles (%) = B	48	48
A/B	1.00	1.17

^{a)} Manufactured by Treibacher Schleifmittel Japan K.K. (Setagaya-ku, Tokyo, Japan)

Table 2

Monoacrylate "MI01A" manufactured by TOA GOSEI K.K. (Minato-ku, Tokyo, Japan)	60.00 parts by weight
Esoxy Acrylate "SP-1509" manufactured by SHOWA KOBUNSHI K.K. (Chiyoda-ku, Tokyo, Japan)	40.00 parts by weight
Photo-polymerization Initiator "Irgacure 907" manufactured by CIBA SPECIALITY CHEMICALS (Minato-ku, Tokyo, Japan)	2.00 parts by weight
Total	102.00 parts by weight

Table 3

Symbol	Size
H	110 μ m
S	60 μ m
P	177 μ m

5

The obtained abrasive material was shaped into the shape of a continuous sheet having a width of 25 mm. On that occasion, the direction of the abrasive material was adjusted so that a longitudinal direction of the ridges forms an angle α of 30 degree with the lateral direction of an abrasive material. The obtained abrasive material sheet was wound up into the shape of a roll.

10

Examples 3 to 6

An abrasive material was obtained and made into the shape of a roll having a width of 25 mm in the same manner as Example 1 except for using a mold sheet made of polypropylene, which has concaves in the shape of an inverted abrasive layer shown in Fig. 1, as well as a coating solution of an abrasive material having a composition shown in Tables 4 and 5 and modifying each size of the prismatic shape into values as shown in Table 6.

15

Table 4

	Example 3	Example 4
Kinds of Abrasive Particles	Alumina 3 μm JIS WA #4000 (Nanko Ceramics K.K., Itabashi-ku, Tokyo, Japan)	Alumina 4 μm JIS WA #3000 (Nanko Ceramics K.K., Itabashi-ku, Tokyo, Japan)
Abrasive Particles	100.00 parts by weight	100.00 parts by weight
Resol-phenol Resin (Nonvolatile Content 60%, Water 20%, Organic Solvent Balance)	66.67 parts by weight	66.67 parts by weight
Propylene Glycol Monomethyl Ether	60.00 parts by weight	30.00 parts by weight
Total	226.67 parts by weight	196.7 parts by weight
Abrasive particles% by weight in abrasive layer	71	71
Abrasive particles% by volume in abrasive layer = A	44	44
Critical pigment volume concentration of Abrasive Particles (%) = B	47	48
A/B	0.94	0.92

Table 5

	Example 5	Example 6
Kinds of Abrasive Particles	Alumina 5 μ m 272LA A5 (Fujimi Incorporated, Nishibiwajima-cho, Nishikasugai-gun, Aichi, Japan)	Diamond 0.5 μ m (Lands Superabrasives, Co., New York, USA)
Abrasive Particles	100.00 parts by weight	100.00 parts by weight
Resol-phenol Resin (Nonvolatile Content 60%, Water 20%, Organic Solvent Balance)	66.67 parts by weight	41.67 parts by weight
Propylene Glycol Monomethyl Ether	30.00 parts by weight	170.00 parts by weight
Total	196.7 parts by weight	311.67 parts by weight
Abrasive particles% by weight in abrasive layer	71	80
Abrasive particles% by volume in abrasive layer = A	44	59
Critical pigment volume concentration of Abrasive Particles (%) = B	46	48
A/B	0.96	1.23

Table 6

Symbol	Size
H	25 μ m
S	15 μ m
W	50 μ m
P	50 μ m
U	0 μ m
β	90 degree
α	20 degree

Comparative Example 1

An abrasive material "Microfinishing Film 272L 20 μm " manufactured by 3M Company (Atherstone, UK) was shaped into the shape of a continuous sheet having a width of 25 mm and wound up into the shape of a roll.

5

Comparative Example 2

An abrasive material "Microfinishing Film 272L 30 μm " manufactured by 3M Company was shaped into the shape of a continuous sheet having a width of 25 mm and wound up into the shape of a roll.

Comparative Example 3

10

An abrasive material "Trizact Film 272LA A5" using aluminum oxide of 5 μm diameter as abrasive particles, and having pyramidal form of abrasive layer, manufactured by 3M Company was shaped into the shape of a continuous sheet having a width of 25 mm and wound up into the shape of a roll.

Comparative Example 4

15

An abrasive material "Lapping Film 0.5 μm Aluminum Oxide type DHE" manufactured by SUMITOMO 3M LIMITED was shaped into the shape of a continuous sheet having a width of 25 mm and wound up into the shape of a roll.

Performance Test 1

20

A roll-shaped abrasive material having a width of 25 mm obtained in Example 1, Example 2, Comparative Example 1, Comparative Example 2 was mounted on a superfinisher Model; SP-100, manufactured by MATSUDA SEIKI K.K., Minoh-shi, Osaka, Japan. A cylindrical workpiece was rotated by a lathe and then the abrasive material was pressed on an outer peripheral surface of the workpiece, which was abraded by gradually feeding the abrasive material. The abrading conditions were such as in Table

25

7.

Table 7

Material of Workpiece	S45C Raw Material; Steel including carbon of 0.45% produced by Sumitomo metal Industries Ltd. (Kitahama, Chuo-ku, Osaka, Japan) (Surface Roughness Ra = 0.43~0.40 μ m)
Abrasive Material Feed Speed	30, 20, 10, 5 mm/min
Workpiece Revolution Number	960 rpm
Oscillation	500 cpm/ 4.0 mm
Cut	0.75, 1.25 mm cut
Polishing Load	3.0, 5.0 kg/cm ²
Backup Rubber Hardness	70 Durometer
Cutting fluid	YUSHIROKEN 50 manufactured by Yushiro Kagaku Kogyo K.K., Chidori, Ohta-ku, Tokyo, Japan

The abraded quantity (mg) was shown in Table 8 and the surface roughness (Ra/ μ m) of the workpiece after being abraded was measured by a probe-type surface roughness meter ("Surftest SV-600" manufactured by Mitsutoyo Corporation, Kawasaki, Kanagawa) to be shown in Table 9. It is understood from Table 8 that the cutting property of Examples 1 and 2 is superior to Comparative Examples 1 and 2 having the same abrasive particle diameter and is intermediate between Comparative Examples 1 and 2 and Comparative Example 3 with a rough count, and additionally is high as compared with Comparative Examples particularly in a range of a low feed speed of the abrasive material, the quantity used of which can be decreased.

Table 8

Abrasive Material	Abrasive Pressure (Pneumatic Pressure kg/cm ²)	Entering Depth (mm)	Feed Speed (mm/min)			
			5	10	20	30
Example 1 MR2.8 SS	3	0.75	14.8	22.4	38.0	48.8
Example 1 MR2.8 SS	5	1.25	18.4	24.6	40	50.6
Example 1 MR2.8 SH	3	0.75	16.8	25.2	43.2	55.8
Example 1 MR2.8 SH	5	1.25	17.8	28.4	45.2	61.6
Example 2 MR4.0 SS	3	0.75	12.4	19.2	31.4	40.6
Example 2 MR4.0 SS	5	1.25	14.6	20.0	33.0	42.8
Example 2 MR4.0 SH	3	0.75	14.2	23.8	39.6	48.2
Example 2 MR4.0 SH	5	1.25	17.0	23.4	40.2	52.2
C.Ex. 1 20 μ m	3	0.75	-	13.8	27.6	34.0
C.Ex. 1 20 μ m	5	1.25	-	15.2	23.0	37.8
C.Ex. 2 30 μ m	3	0.75	-	30.6	47.4	56.6
C.Ex. 2 30 μ m	5	1.25	-	30.2	52.2	61.4

SS: a traveling direction of the abrasive material is for an easy slope side of the ridges

SH: a traveling direction of the abrasive material is for a steep slope side of the ridges

MR4.0: ratio of abrasive particles to resin = 4.0

MR2.8: ratio of abrasive particles to resin = 2.8

Table 9

Abrasive Pressure (Pneumatic Pressure kg/cm ²)	3		5	
	Abrasive Material Feed Speed (mm/min)			
	30	10	30	10
Example 1 MR2.8 SS	0.133	0.094	0.121	0.086
Example 1 MR2.8 SH	0.133	0.103	0.135	0.116
Example 2 MR4.0 SS	0.109	0.079	0.112	0.080
Example 2 MR4.0 SH	0.130	0.085	0.123	0.082
C.Ex. 1 20 μ m	0.131	0.105	0.133	0.108
C.Ex. 2 30 μ m	0.209	0.184	0.204	0.179

SS: a traveling direction of the abrasive material is for an easy slope side of the ridges

SH: a traveling direction of the abrasive material is for a steep slope side of the ridges

MR4.0: ratio of abrasive particles to resin = 4.0

MR2.8: ratio of abrasive particles to resin = 2.8

Performance Test 2

A cylindrical workpiece made of FC material (JIS G 5502 Spheroidal graphite cast iron FCD 700-2) was abraded by using an abrasive material "Microfinishing Film 372L 9 μ m" manufactured by 3M Company to make the surface roughness of an outer peripheral surface thereof into $R_a = 0.040$ to $0.045 \mu\text{m}$. A roll-shaped abrasive material having a width of 25 mm obtained in Example 3, Example 4, Example 5, Example 6 and Comparative Examples 3 was mounted on a superfinisher manufactured by MATSUDA SEIKI K.K. (Minoh-shi, Osaka, Japan). The above-mentioned workpiece was rotated by a lathe and then the abrasive material was pressed on an outer peripheral surface of the

workpiece, which was abraded by gradually feeding the abrasive material. The abrading conditions were such as in Table 10.

Table 10

Material of Workpiece	FC Material (Surface Roughness Ra = 0.040~0.45 μ m)
Abrasive Material Feed Speed	50 mm/min
Workpiece Revolution Number	96 rpm
Oscillation	600 cpm/ 1.5 mm
Cut	0.5 mm cut
Polishing Load	2.0 kg/cm ²
Backup Rubber Hardness	90 Durometer
Cutting fluid	YUSHIROKEN 50 manufactured by Yushiro Kagaku Kogyo K.K., Chidori, Ohta-ku, Tokyo, Japan

5 The change of the surface roughness of the workpiece after being abraded with respect to abrading time was measured by a probe-type surface roughness meter to be shown in Fig. 8. It is understood from Fig. 8 that it took the abrading time of 60 seconds in Comparative Example 3 to remove abrasive marks in the previous process, to achieve finally a finishing roughness Ra=0.033 μ m, while a shorter abrading time of 20 to 40
10 seconds brought a finishing roughness Ra=0.020 to 0.021 μ m in Example 3, an abrading time of 40 seconds brought fine surface roughness Ra=0.023 μ m in Example 4. In Example 5 which employs the same abrasive particles as those of Comparative Example 3, an abrading time of 40 to 60 seconds brought minute finishing having a surface roughness Ra=0.019 to 0.020 μ m, and advantages of the present invention were clearly shown.

15 In Example 6, an abrading time of 60 to 80 seconds removes abrasive marks with 9 μ m in the previous process, a minute finishing of a surface roughness Ra=0.009 μ m was achieved with only one step abrading work. The surface roughness measurements were conducted under a measurement condition of cut off 0.8 mm. However when a measurement condition of cut off 0.08 mm which is more suitable for measuring surface
20 roughness Ra of not more than 0.01 μ m, a remarkable minute finish of Ra=0.004 μ m was obtained.

What is claimed is:

1. A method of abrading a curvilinear surface of workpiece comprising:

5 providing an abrasive article comprising a backing and an abrasive layer placed on the backing, said backing having a major surface, a longitudinal direction, and opposing side edges, each side edge being substantially parallel to said longitudinal direction, said abrasive layer comprising a first layer adhered to said major surface and a second layer comprising abrasive particles dispersed within a binder, said abrasive layer comprising a plurality of parallel rows having a prismatic or a truncated prismatic shape, said parallel
10 rows being aligned at an angle between 10 and 80 degrees with respect to said longitudinal direction;

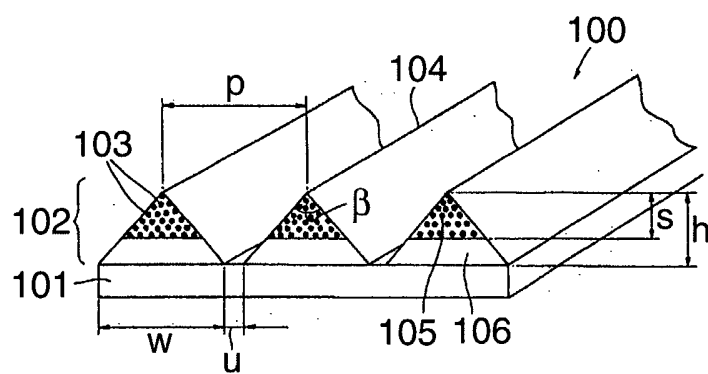
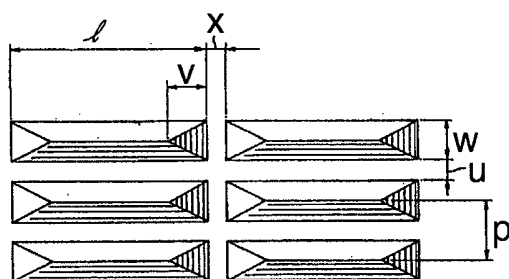
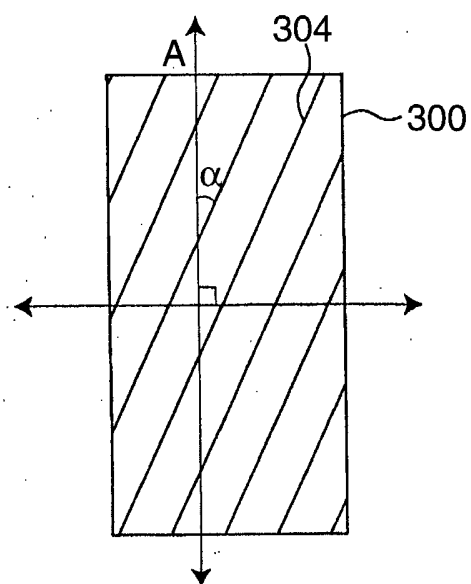
contacting said curvilinear surface of said workpiece with said abrasive article; and
moving said workpiece relative to said abrasive article to at least partially abrade
said curvilinear surface.

15 2. The method of Claim 1 wherein said curvilinear surface of workpiece is an outer peripheral surface of a cylindrical workpiece.

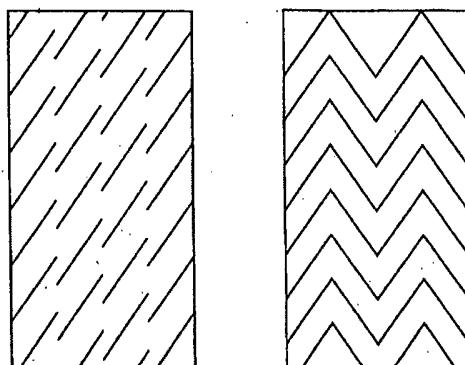
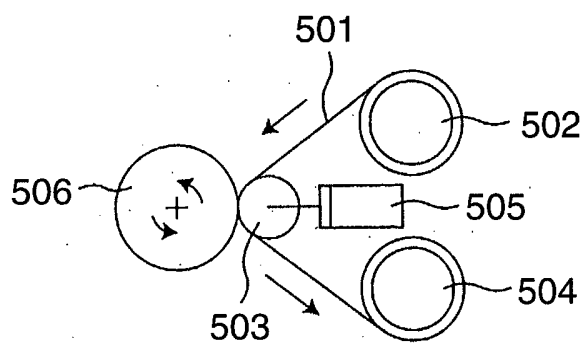
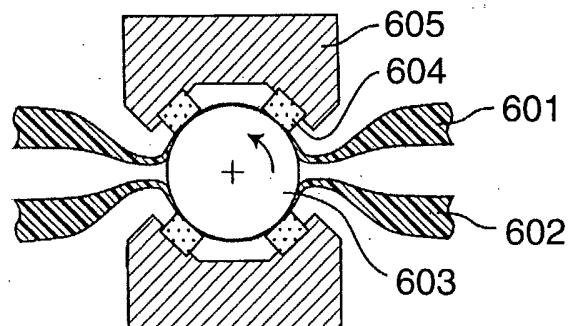
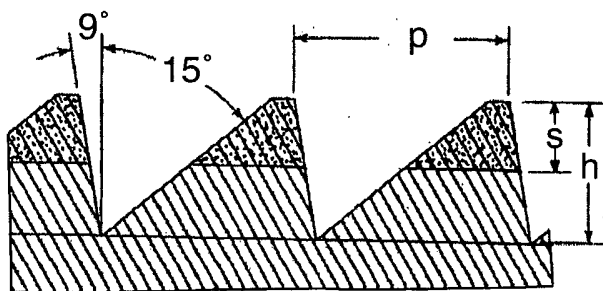
3. The method of Claim 1, wherein concentration of the abrasive particles in the
20 second layer of the abrasive layer is at least 90% of a critical pigment volume concentration.

4. The method of Claim 2, wherein concentration of the abrasive particles in the
25 second layer of the abrasive layer is at least 90% of a critical pigment volume concentration.

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*Fig. 1**Fig. 2**Fig. 3*

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*Fig. 4a**Fig. 4b**Fig. 5**Fig. 6**Fig. 7*

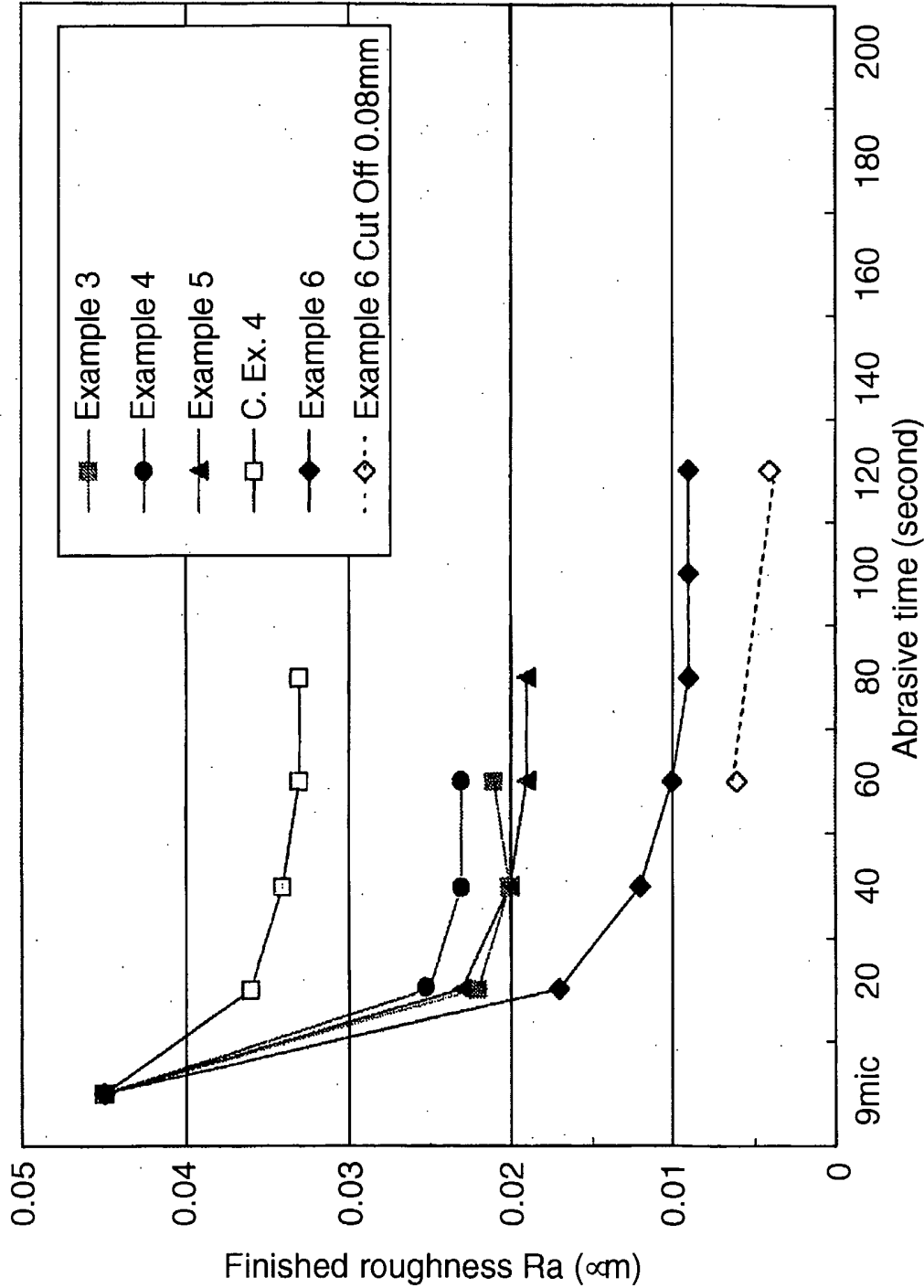


Fig. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/013329

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B24D11/00 B24B5/00 B24B5/42 B24B21/00

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)

IPC 7 B24D B24B

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96/27189 A (MINNESOTA MINING AND MANUFACTURING COMPANY) 6 September 1996 (1996-09-06) page 10, line 14 - page 11, line 10; figures 3-5 -----	1-4

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

22 August 2005

Date of mailing of the international search report

01/09/2005

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International Application No
PCT/US2005/013329

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9627189	A	06-09-1996	CA 2212359 A1 06-09-1996
		DE 69606168 D1 17-02-2000	
		DE 69606168 T2 28-09-2000	
		EP 0812456 A1 17-12-1997	
		JP 11501439 T 02-02-1999	
		WO 9627189 A1 06-09-1996	
		US 5733178 A 31-03-1998	
