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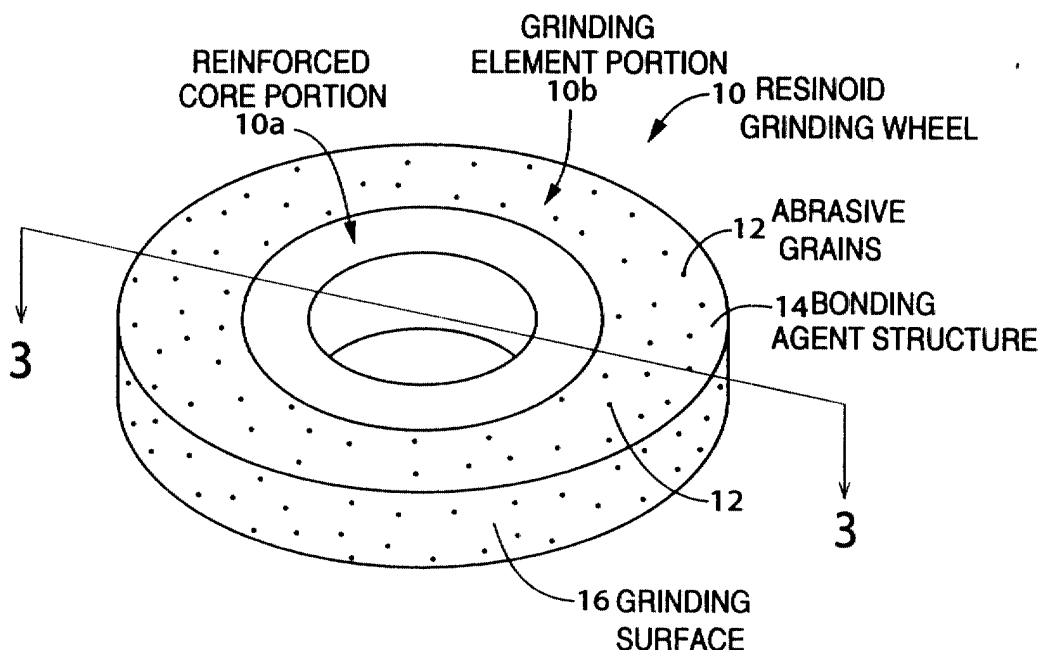
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(54) **Resinoid grinding wheel having core portion made of metallic material**

(57) A grinding wheel (10) including a reinforced core portion (10a) and a grinding portion (10b) which is located radially outwardly of the reinforced core portion and which has an abrasive structure in which abrasive grains (12) are held together by a bonding agent (18) in

the form of a thermosetting resin. The grinding wheel is characterized in that the reinforced core portion is made of a metallic material which has a thermal expansion coefficient ranging from $\alpha-(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$] to $\alpha+(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$], where α represents a thermal expansion coefficient of the grinding portion.

FIG. 1



Description

BACKGROUND OF THE INVENTION

5 Field of the Invention

[0001] The present invention relates in general to a resinoid grindstone or grinding wheel suitably used for a heavy duty grinding operation.

10 Discussion of the Related Art

[0002] In steel making plants, a surface-removing grinding operation is practiced for the purpose of peeling or rec-tifying a rugged surface of an intermediate product such as steel slab, bloom and billet, prior to a rolling operation which is executed in a final step of a process of making a steel product. Such a surface-removing grinding operation is indispensable for assuring a high quality of the final steel product, and is a kind of heavy duty grinding operation in which a large-sized grinding wheel is used since an amount of stock to be removed from a workpiece is, in general, considerably large.

[0003] There is known a resinoid grinding wheel having an abrasive structure in which abrasive grains are held together by a synthetic resin bonding agent (resin bond) principally consisting of a phenol resin or other thermosetting resins. Such a resinoid grinding wheel is advantageously used for a heavy duty grinding operation, owing to an elastic modulus of the synthetic resin bonding agent which is lower than those of other bonding agents such as a glassy bonding agent (vitrified bond), a metallic bonding agent (metal bond) and an electro-deposited bonding agent. A large load applied from the ground workpiece to the abrasive grains during the grinding operation is alleviated or absorbed by elastic deformation of the synthetic resin bonding agent, which deformation is facilitated by the low elastic modulus. As the abrasive grains, for example, alumina (Al_2O_3), silicon carbide (SiC), alumina zirconia ($\text{Al}_2\text{O}_3\text{-ZrO}_2$) or other standard abrasive grains are used.

[0004] In a heavy duty grinding operation, the resinoid grinding wheel is held at its opposite side faces by a pair of flanges having a relatively large diameter, so as to be fixed to a driving shaft of a grinding machine. A radially inner portion of the grinding wheel, which portion has a diameter smaller than that of the flanges, namely, which portion is covered by the flanges, can not be brought into contact with the workpiece, and can not serve to grind the workpiece. Thus, when the diameter of the grinding wheel is reduced to be smaller than that of the flanges, as a result of its repeated services, the grinding wheel is discarded as a waste, which is buried in a waste disposal site. However, such disposal of the waste is more problematic than before, in view of the total annual amount of the waste in Japan which has increased to as large as 100-200 ton, and the consequent shortage of the waste disposal sites in recent years. Under this situation, makers of the grinding wheels have been increasingly required by the users of the grinding wheels, to take the responsibility of collecting the used grinding wheels from the users.

[0005] It might be possible to reutilize or reclaim the used grinding wheels as a fire-resisting material, a shot-blasting material, a polishing material or a non-slip material, by crushing the grinding wheels into small particles. Actually, however, a small percentage of the total amount of the used grinding wheels is reutilized as such materials. Further, even the reutilized grinding wheels are eventually discarded as wastes, not providing any substantial resolution of the above-described environmental problem.

SUMMARY OF THE INVENTION

[0006] It is therefore an object of the present invention to provide a resinoid grinding wheel which is capable of performing a heavy duty grinding operation and which permits a reduced amount of waste produced from the grinding wheel.

[0007] Various studies made by the present inventor in the interest of achieving the above object revealed that the amount of the produced waste can be significantly reduced, by forming a core portion of the resinoid grinding wheel of a metallic material which can be reutilized for various applications. The studies also revealed that the resinoid grinding wheel having the metallic core portion provides a grinding ratio higher than that of a conventional resinoid grinding wheel in which the core portion as well as the grinding portion is provided by an abrasive structure in that abrasive grains are held together by a thermosetting resin.

[0008] Therefore, the above object may be achieved according to the principle of this invention, which provides a grinding wheel including a reinforced core portion and a grinding portion which is located radially outwardly of the reinforced core portion and which has an abrasive structure in which abrasive grains are held together by a thermo-setting resin as a bonding agent. The reinforced core portion is made of a metallic material which has a thermal expansion coefficient ranging from $\alpha -(5 \times 10^{-6}) [1/^\circ\text{C}]$ to $\alpha +(5 \times 10^{-6}) [1/^\circ\text{C}]$, where α represents a thermal expansion

coefficient of the grinding portion. The reinforced core portion is preferably made of a steel, and is more preferably made of a carbon steel. However, the reinforced core portion may be made of other metallic materials such as a stainless alloy and an aluminum alloy which has a low thermal expansion coefficient.

[0009] The grinding wheel of the present invention exhibits an improved grinding ratio owing to the reinforced core portion made of the metallic material. The improved grinding ratio leads to an improved efficiency of grinding of a workpiece and also a prolonged service life of the grinding wheel. In addition, even after the grinding wheel has become incapable of serving to grind a workpiece, the core portion of the grinding wheel can be repeatedly reclaimed or reutilized to form a part of a new grinding wheel, without a risk of brakeage or deformation of the core portion, since the core portion is made of the metallic material. Accordingly, the present grinding wheel significantly contributes to a reduction of the waste in the form of the used grinding wheels. The reutilization of the core portion reduces a material cost for manufacturing the grinding wheel, thereby resulting in a reduced cost for manufacturing the grinding wheel. The present grinding wheel provides another advantage that the grinding wheel can be used in a grinding operation, without, a risk of crack of the grinding portion and removal of a part of the grinding portion from the reinforced core portion, owing to the above-described metallic material whose thermal expansion coefficient is held in a value ranging from $\alpha - (5 \times 10^{-6})$ [$1/^{\circ}\text{C}$] to $\alpha + (5 \times 10^{-6})$ [$1/^{\circ}\text{C}$], where α represents the thermal expansion coefficient of the grinding portion.

[0010] According to a first preferred form of the invention, the grinding wheel further includes a radially intermediate layer which is interposed between an outer circumferential surface of the reinforced core portion and an inner circumferential surface of the grinding portion and which is provided by an organic heat-resisting adhesive.

[0011] In the grinding wheel of the first preferred form of the invention in which the reinforced core portion and the grinding portion are fixed to each other by the organic heat-resisting adhesive, the grinding portion is more reliably prevented from being removed from the reinforced core portion, even in a heavy duty grinding operation in which the grinding wheel is rotated at a high speed and is heated up to have a high temperature.

[0012] According to a second preferred form of the invention, the reinforced core portion has, in an outer circumferential surface thereof, a plurality of annular grooves which are arranged in a direction perpendicular to a radial direction of the reinforced core portion.

[0013] According to a third preferred form of the invention, the reinforced core portion has at least one annular groove formed in an outer circumferential surface thereof, and wherein the grinding portion includes a part which is opposed to a part of the reinforced core portion in an axial direction of the grinding wheel, for preventing displacement of the grinding portion relative to the reinforced core portion in the axial direction.

[0014] In each of the grinding wheels of the second and third preferred forms of the invention, the grinding portion and the reinforced core portion are prevented by the annular groove or grooves, from being displaced relative to each other in the axial direction of the grinding wheel, which corresponds to an axial direction of a driving shaft of a grinding machine when the grinding wheel is mounted on the driving shaft of the grinding machine. Thus, each of the grinding wheels of these preferred forms of the invention permits a grinding operation to be performed more safely, particularly, where the grinding operation is performed by moving a workpiece relative to the grinding wheel in the axial direction of the driving shaft.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The above and other objects, features, advantages and technical and industrial significance of this invention will be better understood by reading the following detailed description of the presently preferred embodiment of the invention, when considered in connection with the accompanying drawings, in which:

Fig. 1 is a perspective view showing a resinoid grinding wheel according to one embodiment of this invention;

Fig. 2 is an enlarged view in cross section of a part of the resinoid grinding wheel of Fig. 1, which part is close to the grinding surface of the resinoid grinding wheel;

Fig. 3 is a cross sectional view taken along line 3-3 of Fig. 1;

Fig. 4 is a flow chart explaining a process of manufacturing the resinoid grinding wheel of Fig. 1;

Fig. 5 is a view schematically illustrating a billet grinding machine on which the resinoid grinding wheel of Fig. 1 is installed for performing a grinding operation;

Fig. 6 is a cross sectional view showing the resinoid grinding wheel of Fig. 1 as mounted on the billet grinding machine of Fig. 5, wherein the cross sectional view is taken in a plane containing the axis of a driving shaft of the billet grinding machine; and

Fig. 7 is a view showing a heavy-duty grinding operation in which a surface of a billet is rectified by the resinoid grinding wheel of Fig. 1, for removing flaws from the billet surface.

DETAILED DESCRIPTION OF

THE PREFERRED EMBODIMENT

[0016] Referring to Figs. 1-7, there will be described a resinoid grinding wheel 10 constructed according to one embodiment of this invention. It is noted that elements which will be described are not necessarily accurately illustrated in the figures, particularly in their relative dimensions.

[0017] Fig. 1 is a perspective view of the resinoid grinding wheel 10, which is advantageously used for a heavy duty grinding operation performed with a billet grinding machine as shown in Fig. 5. This grinding wheel 10 has an outside diameter of 610 mm, an axial length (thickness) of 75 mm and an inside diameter of 203.2 mm, and includes a reinforced core portion 10a and a grinding portion 10b which is located radially outwardly of the reinforced core portion 10a. The reinforced core portion 10a is adapted to have a relatively high mechanical strength, since the same portion 10a has, in its center, a mounting hole which is to be fitted onto a driving shaft 36 of the billet grinding machine. The grinding portion 10b has, in its radially outer end part, a grinding surface 16 which is to be brought into contact with a surface of a workpiece so as to bite into the workpiece surface in a grinding operation. The grinding portion 10b has an abrasive structure in which abrasive grains 12 are held together by a bonding agent structure 14. The abrasive structure of the grinding portion 10b has an abrasive grain percentage of about 50% (which corresponds to a structure 6 as defined in JIS R 6212), and a high density having a porosity of as low as substantially zero.

[0018] In a conventional resinoid grinding wheel, its core portion has a composition which is different from that of its grinding portion located radially outwardly of the core portion such that the core portion has a mechanical strength larger than that of the grinding portion. However, the core portion, as well as the grinding portion, is provided by an abrasive structure in which abrasive grains are held together by a bonding agent structure. In the resinoid grinding wheel 10 of the invention, on the other hand, the core portion 10a is made of a metallic material having a lower modulus of elasticity than the conventional core portion. Further, the metallic material used for the core portion 10a has a thermal expansion coefficient substantially equal to that of grinding portion 10b. More specifically, the thermal expansion coefficient of the metallic material used for the core portion 10a ranges from $\alpha - (5 \times 10^{-6}) [1/^{\circ}\text{C}]$ to $\alpha + (5 \times 10^{-6}) [1/^{\circ}\text{C}]$, where α represents a thermal expansion coefficient of the grinding portion 10b. This range of the thermal expansion coefficient of the core portion 10a is effective to prevent removal of the grinding portion 10b from the reinforced core portion 10a and also crack of the grinding portion 10b. It is noted that the thermal expansion coefficient may be interpreted to mean a linear expansion coefficient, and is obtained according to the following equation:

$$\alpha = (dl/dT)/l_0;$$

where

"l" represents a length;

"T" represents a temperature; and

"l₀" represents a length at 0°C.

[0019] Fig. 2 is an enlarged view in cross section of a part of the grinding portion 10b of the resinoid grinding wheel 10, wherein the part is close to the grinding surface 16. Each of the abrasive grains 12 consists of an alumina (Al₂O₃) abrasive grain which has a grain size of about #20 (i.e. average grain size of about 1000 μm) and is one of cylinder type having a cylindrical shape. The abrasive grains 12 are dispersed substantially evenly in the entirety of the bonding agent structure 14, and some of the abrasive grains 12 are exposed to the exterior of the grinding wheel 10. The abrasive grains 12 have a thermal expansion coefficient of about $7 \times 10^{-6} (1/^{\circ}\text{C})$. The abrasive grains 12 cooperate with the bonding agent structure 14 to constitute an abrasive structure of the grinding portion 10b. The bonding agent structure 14 includes a synthetic resin bonding agent 18 and inorganic fillers 20 which are dispersed substantially evenly in the entirety of the synthetic resin bonding agent 18. The synthetic resin bonding agent 18 consists of a phenol resin or other thermosetting resins having a thermal expansion coefficient of about $50 \times 10^{-6} (1/^{\circ}\text{C})$ which is much larger than that of the abrasive grains 12. A volume ratio of the synthetic resin bonding agent 18 to the inorganic fillers 20 in the bonding agent structure 14 is about 1:1.

[0020] The inorganic filler 20 is prepared by mixing two or more kinds of inorganic particles together with each other, and is provided by a standard filler such as iron sulfide, potassium sulfate and cryolite. The iron sulfide serving as a grinding aid material, and the potassium sulfate and the cryolite serving as an aggregate have been used as fillers of a conventional resinoid grinding wheel designed for a heavy duty grinding operation. The inorganic filler 20 has an average grain size of about 0.5-50 μm and a thermal expansion coefficient ranging from $10 \times 10^{-6} (1/^{\circ}\text{C})$ to $100 \times 10^{-6} (1/^{\circ}\text{C})$. The grinding portion 10b, which is constituted by the abrasive grains 12, the synthetic resin bonding agent 18

and the inorganic fillers 20 which have the respective thermal expansion coefficients as described above, has a thermal expansion coefficient α ranging from 10×10^{-6} ($1/^{\circ}\text{C}$) to 14×10^{-6} ($1/^{\circ}\text{C}$). For example, the grinding portion 10b may be formed by mixing the abrasive grains 12 into the bonding agent structure 14 such that the grinding portion 10b has an abrasive grain percentage of 50%, wherein the bonding agent structure 14 consists of phenol resin and iron sulfide as the respective synthetic resin bonding agent 18 and inorganic filler 20 such that a volume ratio of the synthetic resin bonding agent 18 to the inorganic filler 20 is about 0.6-0.7 (the bonding agent 18 : the filler 20 = 60-70 : 100). With this composition, the thermal expansion coefficient α of the grinding portion 10b is about 12×10^{-6} ($1/^{\circ}\text{C}$) at a room temperature.

[0021] Fig. 3 is a cross sectional view taken along a line 3-3 of Fig. 1. As shown in Fig. 3, the reinforced core portion 10a has, in its outer circumferential surface 22, a succession of recesses and protrusions which are alternately arranged in a vertical direction as viewed in Fig. 3, namely, a direction perpendicular to the radial direction of the core portion 10a. In other words, a plurality of annular grooves are formed in the outer circumferential surface 22 of the core portion 10a, such that the annular grooves are arranged in the axial direction of the core portion 10a. The outer circumferential surface 22 includes protruded surfaces 24; recessed surfaces 26 which correspond to bottom surfaces of the respective annular grooves and have a diameter smaller than that of the protruded surfaces 24; and shoulder surfaces 25 which connect the respective protruded and recessed surfaces 24, 26. The protruded and recessed surfaces 24, 26 are substantially parallel to the grinding surface 16 of the grinding portion 10b, while the shoulder surfaces 25 are substantially perpendicular to the grinding surface 25. Similarly, the grinding portion 10b has a plurality of annular grooves formed in an inner circumferential surface 28 of the grinding portion 10b, such that the inner circumferential surface 28 of the grinding portion 10b has a shape complementary to that of the outer circumferential surface 22 of the core portion 10a, whereby the grinding portion 10b is fitted on the core portion 10a. This arrangement in which the core portion 10a and the grinding portion 10b include respective parts which are opposed to each other in the axial direction of the grinding wheel 10 is effective to prevent displacement of the grinding portion 10b relative to the core portion 10a in the axial direction.

[0022] The grinding wheel 10 further includes a radially intermediate layer 30 which is interposed between the outer circumferential surface 22 of the reinforced core portion 10a and the inner circumferential surface 28 of the grinding portion 10b. The radially intermediate layer 30 is formed of an organic heat-resisting adhesive having a certain degree of heat resistance that is not smaller than that of the synthetic resin bonding agent 18 contained in the bonding agent structure 14. For example, this organic heat-resisting adhesive may consist of phenol adhesive or polyimide adhesive. Preferably, this organic heat-resisting adhesive consists of the same kind of adhesive as the synthetic resin bonding agent 18.

[0023] The resinoid grinding wheel 10 as constructed as described above may be manufactured by a method illustrated in the flow chart of Fig. 4. Initially, a bond-powder preparing step S1 is implemented to mix the inorganic fillers 20 with a powder of phenol resin or other synthetic resin bonding agents, for thereby preparing a so-called "bond powder". The bond-powder preparing step S1 is followed by a body preparing step S2 in which the bond powder, the abrasive grains 12 and a liquid of phenol resin or other synthetic resin bonding agents are mixed together under stirring to prepare a so-called "body". In this instance, where the grinding wheel 10 is manufactured such that the bonding agent structure 14 includes a reinforcing agent such as a glass fiber, the reinforcing agent is mixed with the above-described materials in this step. The proportions of the respective materials of the mixture obtained in each of the steps S1 and S2 are suitably determined such that the abrasive grain percentage and the volume ratio have the above-described respective values.

[0024] The body preparing step S2 is followed by a pressing step S3, in which the heat-resisting adhesive in the form of liquid phenol resin MWB-5101 (which is available from Meiwa Kasei Co., Ltd.) is applied on the outer circumferential surface 16 of the metallic core portion 10a, and the core portion 10a is then placed in a suitable position within a metal mold. The body, which has been prepared in the above-described body preparing step S2, is provided on the radially outer side of the core portion 10a, so as to be then subjected to a hot-pressing operation performed at a temperature of 180-200 $^{\circ}\text{C}$, for thereby obtaining an intermediate product. The pressing step S3 is followed by a curing step S4 in which the intermediate product is subjected to an after-cure treatment at a temperature that is determined depending upon the composition of the bonding agent structure 14. With the implementation of the curing step S4, a final product in the form of the resinoid grinding wheel 10 as shown in Fig. 1 is obtained.

[0025] Fig. 5 is a view schematically illustrating a billet grinding machine on which the resinoid grinding wheel 10 manufactured as described above is installed for performing a grinding operation. This billet grinding machine is designed to grind a surface of a prism-shaped steel billet 32 for thereby removing or eliminating cracks, flaws and other irregularities on the surface of the billet 32, prior to a rolling step or a cutting step (not shown) which is executed in a final step of a process of making a steel product. The billet grinding machine has a billet carriage 34 on which the billet 32 as the workpiece is disposed. During the grinding operation, the billet carriage 34 is given a reciprocating motion in the longitudinal direction of the billet 32, i.e., in a horizontal direction that is perpendicular to the plane of Fig. 5. The billet grinding machine further has a driving shaft 36 which is located above the billet carriage 34 and on which the

resinoid grinding wheel 10 is mounted so as to be rotatable by the driving shaft 36.

[0026] Fig. 6 is a cross sectional view showing the resinoid grinding wheel 10 as mounted on the driving shaft 36 of the billet grinding machine of Fig. 5, wherein the cross sectional view is taken in a plane containing an axis of the driving shaft 36. As shown in Fig. 6, the grinding wheel 10 is fitted on a small-diameter end portion of the driving shaft 36, and is fixed to the driving shaft 36 by a pair of flanges 37, 38 and a nut 39. The outside diameter of the core portion 10a is slightly smaller than the outside diameter of the flanges 37, 38. A radially inner part of the grinding portion 10b, which part has a diameter smaller than that of the flanges 37, 38, namely, which part as well as the core portion 10a is covered by the flanges 37, 38, can not be brought into contact with the workpiece to serve as a grinding element for grinding the workpiece.

[0027] The driving shaft 36 is driven by a motor 42 whose rotational motion is transmitted to the shaft 36 by means of belts 40, 41 which are indicated by respective one-dot chain lines in Fig. 5. The motor 42, the driving shaft 36 and other elements are disposed on a cross slide 48 which is movable in the rightward and leftward directions as viewed in Fig. 5 by a reciprocating motion of a piston 46 of a cross-slide cylinder 44. On the cross slide 48, there is further disposed a pivot arm 56 which is pivotable about an pivot shaft 54 and which rotatably holds the driving shaft 36 in its distal end portion. The pivot arm 56 is given a pivot motion which is caused by reciprocating motions of pistons 52, 52 of pivot-arm cylinders 50, 50, namely, by a difference between travel distances by which the pistons 52, 52 protrude from the respective pivot-arm cylinders 50, 50. The pivot-arm cylinders 50, 50 are operable by operation of a lever 58 which is carried out by an operator who is positioned on the left side of the billet grinding machine as viewed in Fig. 5. The resinoid grinding wheel 10 is movable by the activation of the cross-slide cylinder 44 in the rightward and leftward direction as indicated by an arrow B, and also by the activations of the respective pivot-arm cylinders 50, 50 in the upward and downward direction as indicated by an arrow C, so that the grinding wheel 10 can be moved to any desired position on a plane perpendicular to the longitudinal direction of the billet 32. Thus, the grinding wheel 10 and the billet 32 can be moved relative to each other not only in the longitudinal direction of the billet 32 but also in a direction perpendicular to the longitudinal direction of the billet 32, for thereby grinding the surface of the billet 32 so as to remove a multiplicity of flaws 60 from the billet 32 as shown in Fig. 7.

[0028] Tests were conducted to evaluate performances of the resinoid grinding wheel 10, by using the resinoid grinding wheel 10 as Example 1 and two grinding wheels as Comparative Examples 1 and 2. The resinoid grinding wheel 10 as Example 1 was prepared according to the process represented by the flow chart of Fig. 4.

[0029] All the grinding wheels used in the tests were identical in dimensions to each other. Each of all the grinding wheels had an outside diameter of 610 mm, an axial length (thickness) of 75 mm and an inside diameter of 203.2 mm. The core portion of each of all the grinding wheels had an outside diameter of 360 mm. As well as in dimensions, all the grinding wheels were identical in composition of the grinding portion to each other. The grinding portion of each of all the grinding wheels had a thermal expansion coefficient α of 12×10^{-6} ($1/^{\circ}\text{C}$) at a room temperature. However, the grinding wheels were different in composition of the core portion from each other. The core portion 10a of the grinding wheel 10 of Example 1 was made of a carbon steel (S45C) whose thermal expansion coefficient was 12×10^{-6} ($1/^{\circ}\text{C}$) at a room temperature. The core portion of the grinding wheel of Comparative Example 1 was made of an aluminum (simple substance) whose thermal expansion coefficient was 23×10^{-6} ($1/^{\circ}\text{C}$) at a room temperature. The core portion of the grinding wheel of Comparative Example 2 was made of a conventional abrasive solid mass whose thermal expansion coefficient was 13×10^{-6} ($1/^{\circ}\text{C}$) at a room temperature. In the grinding wheel of Comparative Example 2 in which the core portion was made of the abrasive solid mass, there was not provided an adhesive to be interposed between the core portion and the grinding portion.

[0030] Prior to the tests, two sets of the above-described grinding wheels of Example 1 and Comparative Examples 1 and 2 were prepared. For evaluating a safety performance of each grinding wheel, a rotation breakdown test was conducted by using one of the two sets. For evaluating a grinding performance of each grinding wheel, a grinding operation test was conducted by using another one the two sets.

[0031] Table 1 shows results of the rotation breakdown test. The "Breakdown Rotational Speed" indicated in Table 1 represents the number of revolutions per minutes at which each grinding wheel was broken. The "Breakdown Peripheral Speed" represents a peripheral speed (m/s) at which each grinding wheel was broken. The "Safety Factor" represents a ratio of the breakdown peripheral speed to 80 (m/s) that corresponds to a peripheral speed suitable for an actual heavy duty grinding operation.

[0032] As is apparent from Table 1, the grinding wheel 10 of the present invention of Example 1 exhibited an excellent safety performance. The "Safety Factor" of the grinding wheel 10 of Example 1 was 2.16. This value 2.16 is sufficiently higher than 2.00 that is a minimum value generally required in a grinding operation. The grinding wheel 10 of Example 1 exhibited a strength that was 1.05 times as high as that of the conventional grinding wheel of Comparative Example 2. The grinding wheel of Comparative Example 1, on the other hand, exhibited a strength that was 0.76 times as high as that of the conventional grinding wheel of Comparative Example 2 and was accordingly lower than that of the conventional grinding wheel of Comparative Example 2, although its core portion was made of the metallic material like the core portion of the grinding wheel as Example 1.

[Table 1]

	Breakdown Rotational Speed (r.p.m.)	Breakdown Peripheral Speed (m/sec.)	Safety Factor (v/80)
Example 1	5405	173	2.16
Comparative Example 1	3907	125	1.56
Comparative Example 2	5148	164	2.05

[0033] The grinding operation test was conducted on the billet grinding machine as illustrated in Fig. 5, in the following conditions:

Material of Workpiece: SUS430

Dimensions of Workpiece: 130×130×2600 mm

Peripheral Speed of the Grinding Wheel: 80 m/s

Speed of Movement of Billet Carriage: 0.5 m/s

[0034] Results of the grinding operation test are shown in Table 2. The "Amount of Wear of Grinding Wheel" indicated in Table 2 represents an amount of reduction in weight of each grinding wheel as a result of the grinding operation. The "Amount of Stock Removed from Workpiece" represents an amount of reduction in weight of the workpiece as a result of the grinding operation. The "Grinding Ratio" represents a ratio of the "Amount of Stock Removed from Workpiece" to the "Amount of Wear of Grinding Wheel". All the values of Example 1 indicated in Table 2 are values relative to the respective values of Comparative Example 2 each of which is represented by 100. For example, the value "146" in "Grinding Ratio" of Example 1 means that the grinding ratio of Example 1 is 1.46 times as high as that of Comparative Example 2. It is noted that the grinding operation with each of all the grinding wheels was carried out for 20 minutes with a constant current supplied to the billet grinding machine.

[0035] As shown in Table 2, Example 1 in the form of the resinoid grinding wheel 10 of the present invention exhibited the grinding ratio 1.46 times as high as that of Comparative Example 2 in the form of the conventional resinoid grinding wheel. It is assumed that this relatively high grinding ratio was advantageously provided by a physical property of the composition of the core portion 10a of the grinding wheel 10. That is, the core portion 10a of the grinding wheel 10 is constituted by the steel whose elastic modulus is higher than the abrasive solid mass that constitutes the core portion of the conventional grinding wheel of Comparative Example 2, whereby the grinding portion 10b of the grinding wheel 10 was displaced away from the workpiece by a comparatively small distance during the grinding operation, so that the grinding wheel 10 was capable of more efficiently removing the stock from the workpiece, than the conventional grinding wheel of Comparative Example 2. Accordingly, the grinding wheel 10 of Example 1 exhibited the grinding ratio higher than that of the conventional grinding wheel of Comparative Example 2.

[0036] The grinding wheel of Comparative Example 1 suffered from being cracked at an interface between the core portion and the grinding portion during the grinding operation test. Thus, the test with Comparative Example 1 was suspended due to a possibility of dangerous breakage of the grinding wheel. It is considered that the cracking of Comparative Example 1 was caused by a large difference between the thermal expansion coefficient of the grinding portion and the thermal expansion coefficient of the core portion which is made of aluminum, since amount of heat generation is generally large in a heavy duty grinding operation like the present grinding operation test.

[Table 2]

	Amount of Wear of Grinding Wheel	Amount of Stock Removed from Workpiece	Grinding Ratio
Example 1	89	130	146
Comparative Example 1	(Test was suspended due to crack of grinding wheel.)		
Comparative Example 2	100	100	100

[0037] As is clear from the results of the grinding operation test, the reinforced core portion 10a made of the steel is effective to significantly improve the grinding ratio. The improved grinding ratio leads to an improved efficiency for grinding a workpiece and also a prolonged service life of the grinding wheel 10. In addition, even after the grinding wheel 10 has become incapable of serving to grind a workpiece, the core portion 10a of the grinding wheel 10 can be repeatedly reutilized to form a part of a new grinding wheel 10, without a risk of brakeage or deformation of the core

portion 10a, since the core portion 10a is made of the metallic material. Accordingly, the present grinding wheel 10 significantly contributes to a reduction of the waste in the form of the used grinding wheels. The reutilization of the core portion 10a reduces a material cost for manufacturing the grinding wheel 10, thereby resulting in a reduced cost for manufacturing the grinding wheel 10. The present grinding wheel 10 provides another advantage that the grinding wheel 10 can be used in a grinding operation, without a risk of crack of the grinding portion 10b and removal of a part of the grinding portion 10b from the reinforced core portion 10a, owing to the thermal expansion coefficient of the steel-made reinforced core portion 10a which is substantially equal to that of the grinding portion 10b.

[0038] The repeated reutilizations of the core portion 10a requires a cost for collecting the used grinding wheel. Actually, grinding wheels designed for a heavy duty grinding operation are used by limited users who generally purchase the grinding wheels directly from makers of the grinding wheels. Thus, the used grinding wheels can be collected by the makers from the users at the same time that new grinding wheels are delivered by the makers to the users, thereby making it possible to reduce the cost for collecting the used grinding wheel. Thus, the reutilizations of the core portion 10a provide a positive economic effect, reducing a material cost for manufacturing the grinding wheel 10. It is noted that the collected core portion 10a may be melted to be reutilized where the collected core portion 10a has a breakage or deformation thereof.

[0039] In the resinoid grinding wheel 10 of the present embodiment of the invention, in which the reinforced core portion 10a and the grinding portion 10b are fixed to each other by the organic heat-resisting adhesive in the form of the liquid phenol resin adhesive which is interposed therebetween, the grinding portion 10b is more reliably prevented from being removed from the reinforced core portion 10a, even in a heavy duty grinding operation in which the grinding wheel is rotated at a high speed and is heated up to have a high temperature.

[0040] In the resinoid grinding wheel 10 of the present embodiment of the invention, the reinforced core portion 10a and the grinding portion 10b are prevented owing to the annular grooves formed in the outer circumferential surface 22 of the reinforced core portion 10a, from being displaced relative to each other in the axial direction of the grinding wheel 10, which corresponds to an axial direction of the driving shaft 36 of the billet grinding machine when the grinding wheel 10 is mounted on the driving shaft 36. Thus, the grinding wheel 10 permits a grinding operation to be performed more safely, particularly, where the grinding operation is performed by moving a workpiece relative to the grinding wheel 10 in the axial direction of the driving shaft 36.

[0041] While the presently preferred embodiment of the present invention has been described above with a certain degree of particularity, by reference to the accompanying drawings, it is to be understood that the invention is not limited to the details of the illustrated embodiment, but may be otherwise embodied.

[0042] While the reinforced core portion 10a is made of the steel in the above-illustrated embodiment, the core portion 10a may be made of a stainless alloy, an aluminum alloy having a low thermal expansion coefficient, or other metallic materials having a thermal expansion coefficient ranging from α $-(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$] to α $+(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$], where α represents the thermal expansion coefficient of the grinding portion 10b.

[0043] In the above-illustrated embodiment, the reinforced core portion 10a has the succession of the recesses and protrusions, i.e., the plurality of annular grooves formed in the outer circumferential surface 22. However, the number of the annular grooves does not necessarily have to be at least two, but may be only one. In addition, while the recesses and protrusions are defined by the flat surfaces 24, 26 which are parallel to the grinding surface 16 of the grinding portion 10b in the above-illustrated embodiment, the recesses and protrusions may be defined by, for example, a succession of V-shaped surfaces and inverted-V-shaped surfaces, or a succession of U-shaped surfaces and inverted-U-shaped surfaces. It is noted that the provision of the recesses and protrusions or annular grooves in the outer circumferential surface 22 of the reinforced core portion 10a is not essential, and the circumferential surface 22 may be flat as viewed in a cross section taken by a plane containing the axis of the grinding wheel 10, particularly, where the grinding wheel 10 is designed to be used for a grinding operation in which a load applied to the grinding wheel 10 in the axial direction is not so large.

[0044] While the body prepared in the body preparing step 2 is subjected to the hot-pressing operation in the above-illustrated embodiment, the body may be subjected to a cold-pressing operation in stead of the hot-pressing operation.

[0045] It is to be understood that the invention may be embodied with various other changes, modifications and improvements, which may occur to those skilled in the art, without departing from the spirit and scope of the invention defined in the following claims.

A grinding wheel (10) including a reinforced core portion (10a) and a grinding portion (10b) which is located radially outwardly of the reinforced core portion and which has an abrasive structure in which abrasive grains (12) are held together by a bonding agent (18) in the form of a thermosetting resin. The grinding wheel is characterized in that the reinforced core portion is made of a metallic material which has a thermal expansion coefficient ranging from α $-(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$] to α $+(5 \times 10^{-6})$ [$1/^{\circ}\text{C}$], where α represents a thermal expansion coefficient of the grinding portion.

Claims

1. A grinding wheel (10) including a reinforced core portion (10a) and a grinding portion (10b) which is located radially outwardly of said reinforced core portion and which has an abrasive structure in which abrasive grains (12) are held together by a bonding agent (18) in the form of a thermosetting resin, said grinding wheel being **characterized in that:**

said reinforced core portion is made of a metallic material which has a thermal expansion coefficient ranging from $\alpha \cdot (5 \times 10^{-6}) [1/^{\circ}\text{C}]$ to $\alpha \cdot (5 \times 10^{-6}) [1/^{\circ}\text{C}]$, where α represents a thermal expansion coefficient of said grinding portion.

2. A grinding wheel (10) according to claim 1, further including a radially intermediate layer (30) which is interposed between an outer circumferential surface (22) of said reinforced core portion (10a) and an inner circumferential surface (28) of said grinding portion (10b) and which is provided by an organic heat-resisting adhesive.

3. A grinding wheel (10) according to claim 1 or 2, wherein said reinforced core portion (10a) has, in an outer circumferential surface (22) thereof, a plurality of annular grooves which are arranged in a direction perpendicular to a radial direction of said reinforced core portion.

4. A grinding wheel (10) according to claim 1 or 2, wherein said reinforced core portion (10a) has at least one annular groove formed in an outer circumferential surface (22) thereof, and wherein said reinforced core portion (10a) and said grinding portion (10b) include respective parts which are opposed to each other in an axial direction of said grinding wheel, for preventing displacement of said grinding portion relative to said reinforced core portion in said axial direction.

5. A grinding wheel (10) according to any one of claims 1-4, wherein said reinforced core portion (10a) is made of a steel.

6. A grinding wheel (10) according to any one of claims 1-4, wherein said reinforced core portion (10a) is made of a stainless alloy.

FIG. 1

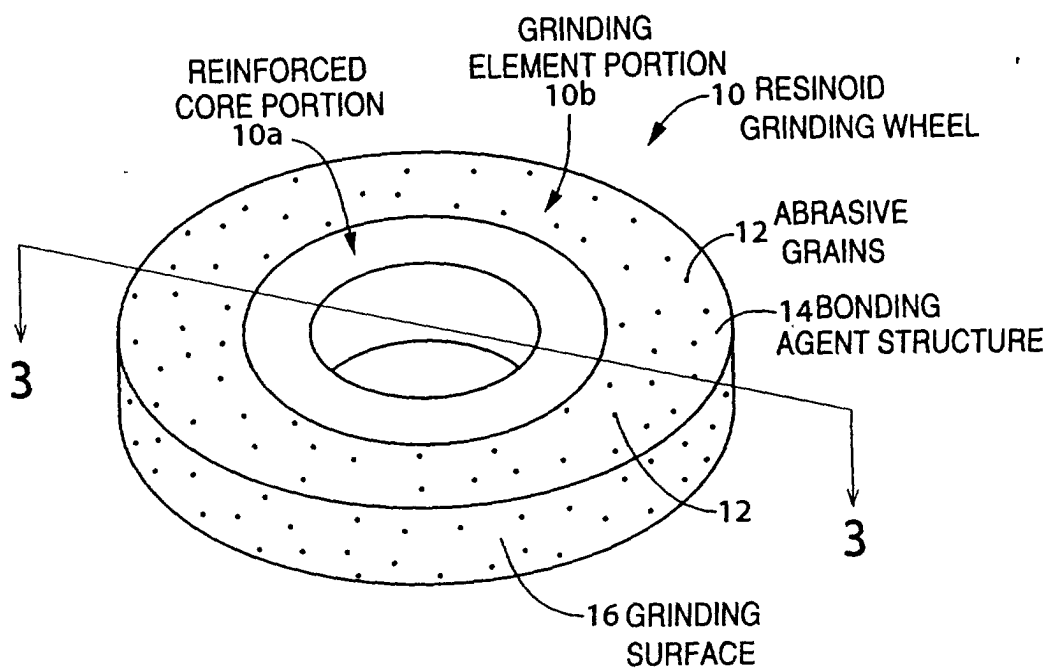


FIG. 2

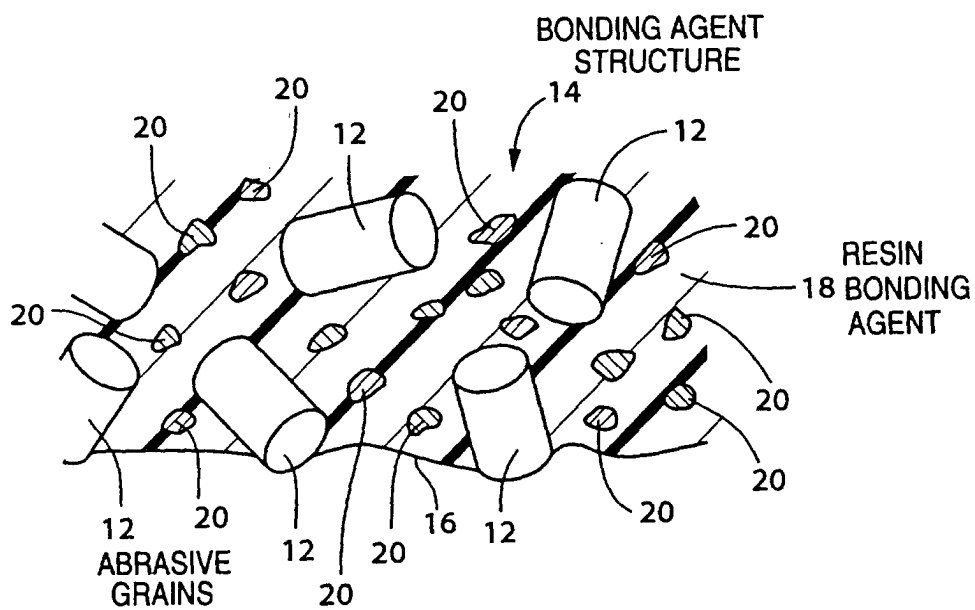


FIG. 3

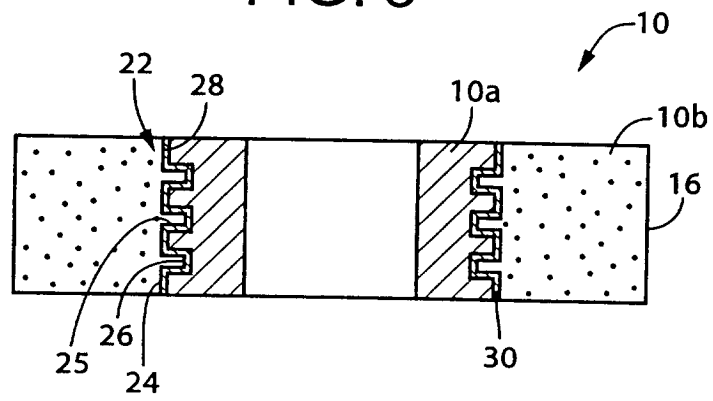


FIG. 4

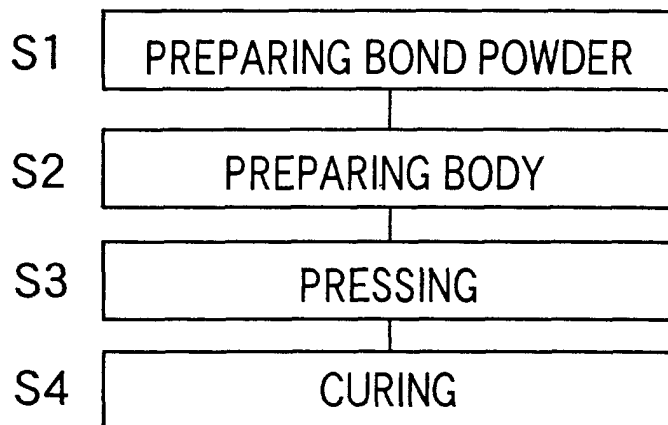


FIG. 5

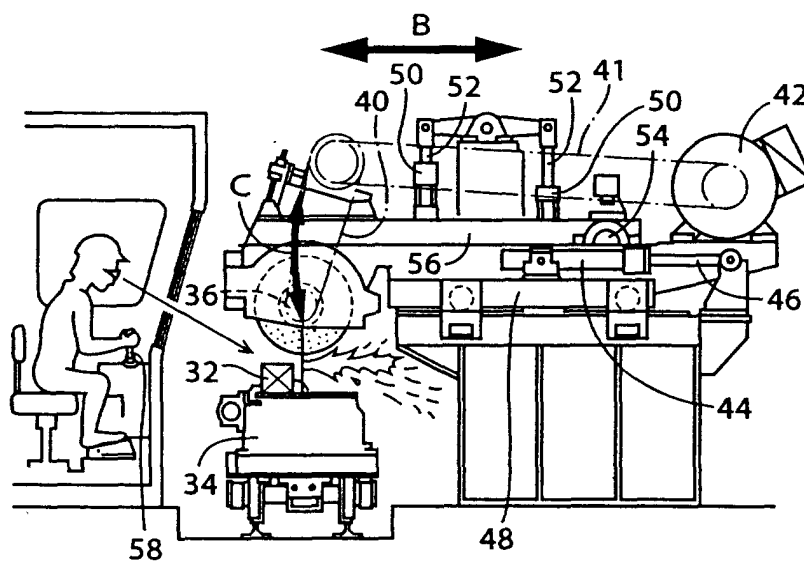


FIG. 6

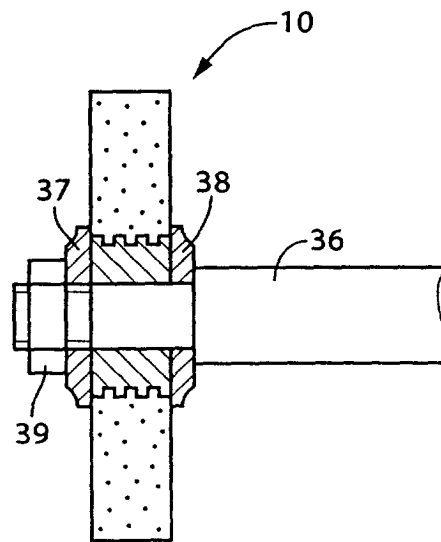


FIG. 7

