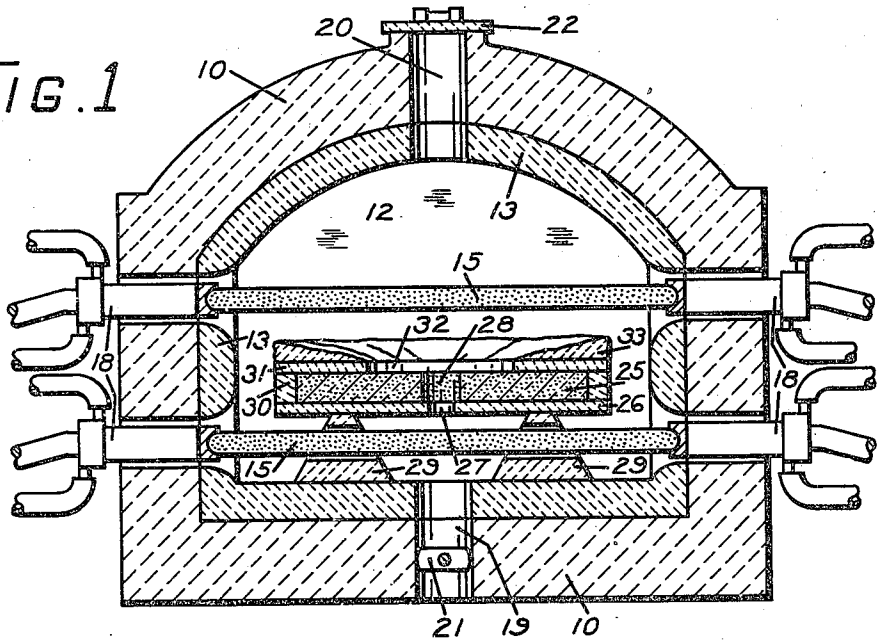
March 24, 1936. W. L. HOWE 2,034,721

GRINDING WHEEL AND METHOD OF MAKING THE SAME

Filed Sept. 6, 1933

FIG. 1



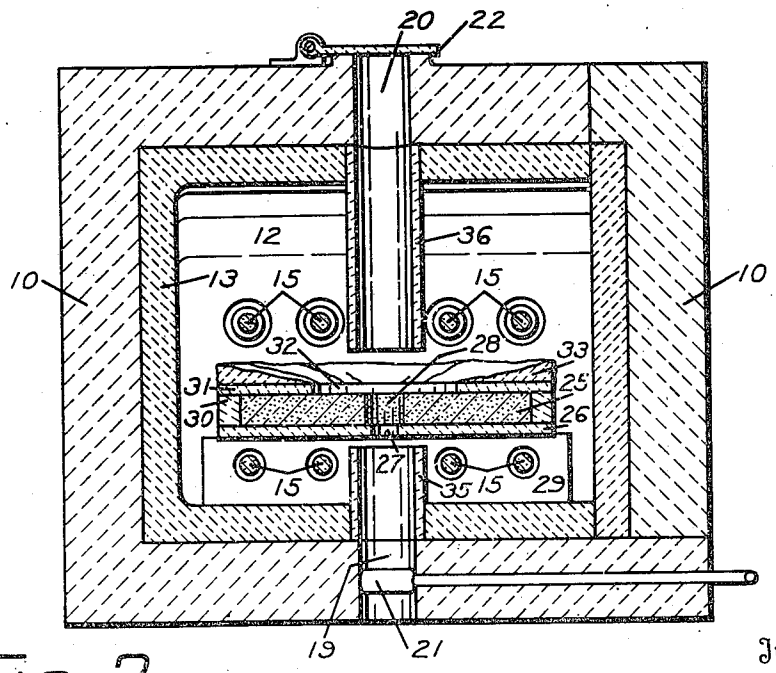


FIG. 2

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GRINDING WHEEL AND METHOD OF MAKING THE SAME

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10 Claims. (Cl. 51—278)

This invention relates to grinding wheels, and more particularly to a grinding wheel which is made of abrasive grains united into an integral body by a vitrified ceramic bonding material and to a method of making the same.

It has been determined, as set forth in the copending application of Whitcomb and Wagner, Serial No. 678,816, filed July 3, 1933, that a grinding wheel when in use is subjected to two major destructive forces which tend to break it; namely, the stress set up by the centrifugal force due to rotation of the wheel, and the stress introduced by differential temperatures in the wheel body resulting from the heat of grinding on its periphery. It has been found that each of these stresses exists as a tangential tensile stress and the effect of one or of a combination of the two is to produce a maximum tensional stress at the edge of the central hole of the rotating wheel. Hence, when a grinding wheel breaks, the crack must start at the edge of the central hole and move outwardly in a radial direction.

It is accordingly a primary object of this invention to produce a grinding wheel which is highly resistant to the disruptive forces met thereby during normal grinding use, and particularly to provide a method of strengthening a grinding wheel of standard composition and structure.

In accordance with the standard methods of making vitrified grinding wheels, a mixture of abrasive grains and suitable vitrifiable ceramic nding materials in the required proportions and with sufficient moisture to form a plastic mass is molded into the form of a wheel, allowed to dry and shaped to provide for the dimensions required. At this stage of the process the wheel, which is only loosely held together by the dried bonding material and is in a crumbly, semi-plastic or friable condition is commonly referred to as a "green" wheel.

In order to harden the "green" wheel so as to render it suitable for abrasive purposes, it is fired to relatively high temperatures to vitrify the bond, which may be carried out in various types of kilns. During this operation, the bonding material is heated to approximately its melting point, the exact temperature depending upon the material used, in order to render it plastic and develop its cohesive and adhesive strength between the grains. After a short "soak" at this high temperature, the wheels are cooled to solidify the plastic, melted glass bond. In practice, it is customary to place the "green" wheel in a sagger in which it is laid upon its flat side upon a supporting bed of sand. A number of these saggers, each containing a "green" wheel are then placed upon each other in the kiln to form piles or stands and fired, as thus arranged, according to the methods usually adopted, which are well known in the art.

When the grinding wheel is fired and cooled in this manner, cooling of the wheel is found to occur more rapidly at its peripheral portion than from the sides or central portion. Thus, a temperature differential is set up between the peripheral and central portions. This temperature differential is set up at the commencement of the cooling period and causes the peripheral concentric portions of the wheel to contract relative to the inner portions. But since the bond at these high temperatures is in a plastic condition and thus unable to retain any strain, this differential contraction can and will take place without inducing any permanent strain in the wheel. Furthermore, if this same temperature differential is now maintained as cooling proceeds through the annealing range of temperatures where the bond changes from the soft plastic condition to the rigid state, the wheel will still be with little or no strain. However, in cooling the wheel body from this point to room temperature, it follows that the central concentric portions of the wheel must cool through a greater temperature range than the peripheral portions, and thus the central portions contract to a greater degree; hence, the central zone of the wheel is in a state of tensional strain and the peripheral zone is subjected to a compressional strain.

It is to be noted that these strains are due to imperfect annealing of the wheel body and are distributed throughout the wheel as a whole, stressing it from the center to the periphery. These strains exist entirely independently of other kinds of strain and should not be confused with those contact strains set up at the points of contact of the individual posts of bond and the abrasive grains, which are caused by a difference in the coefficients of expansion of the glass bond and the abrasive material. Hence, it can be seen that the presence of this tensional annealing stress about the hole of the wheel is an important factor contributing to wheel breakages since the effective resistance of the grinding wheel to rupture during use must be measured by the difference between the strength value expressing the tensile strength characteristic of the bonded structure and the actual amount of residual tensile stress existing therein which is produced during the cooling period of bond solidification. It will therefore be appreciated that this tensional stress set up by this detrimental annealing strain combines with the centrifugal and heat differential stresses set up during grinding and so further tends to disrupt the wheel.

It is a further object of this invention to overcome the disadvantages involved in the prior procedure of making articles of this type and to provide a method of making a vitrified grinding wheel in accordance with which these detrimental annealing strains are minimized and particu-

larly one in which the annealing strains in the wheel are of such a character that the wheel is materially strengthened.

A still further object is to provide a vitrified grinding wheel in which the inner portions of the wheel adjacent to the center are subjected to compressional rather than tensional forces and the central portion of the wheel is thereby strengthened and made highly resistant to the destructive tensional forces met with in use during the grinding operation.

With these and other objects in view, as will be apparent to one skilled in the art, this invention resides in the article herein described as well as to the process of making the same, as covered by the claims appended hereto.

Referring to the drawing, which shows several embodiments of this invention:

Fig. 1 is a vertical section of an electric furnace, showing diagrammatically one method of carrying out the invention; and

Fig. 2 is a vertical section, taken at right angles of Fig. 1, showing a modified construction by which another method may be employed to carry out the invention.

In accordance with one aspect of this invention, I propose to lessen the residual tensional strain within the inner or central zone heretofore caused by imperfectly annealing a vitrified grinding wheel and so make the wheel materially stronger than one made by the standard methods. I furthermore propose to provide a wheel of high resistance to disruptive forces of grinding by imposing on the bonding material of the inner zone a compressional stress which effectively resists and opposes the tangential tensional stresses met with during grinding. This is preferably accomplished by so cooling the wheel as to set up a temperature difference throughout the wheel at the commencement of cooling as will cause the central portion of the wheel to contract relative to the peripheral portion, but while the bond is soft and plastic it will be unable to retain any permanent strain. This same temperature is then maintained as the bond further cools and passes through the annealing range, where it changes from the plastic to the solid, rigid condition; but, as long as this temperature difference is maintained, no strain will be introduced in the solidified mass. However, in the final stage of bringing the solid body to room temperature, I cool the peripheral portion through a greater temperature range than the central portion, in order to eliminate the temperature difference therebetween, thus causing the peripheral portion to contract relative to the central portion and shrink thereon, thereby resulting in setting up a residual compressional strain at the central hole and a tensional strain at the peripheral portion. This reverse type of strain resulting from the compressional stress within the bond at the center of a solid wheel or adjacent to the hole at the center of the wheel resists such tensional disruptive forces as may be applied during the use of the wheel and must be entirely neutralized before the real strength of the bonded wheel structure is called upon to resist the tensional stresses set up by the major forces tending to disrupt the grinding wheel during use. Consequently, this compressional stress may be added to the actual real strength of the bonded wheel structure in determining the total effective strength of the wheel during use.

One method by which this may be accomplished is by firing the ceramic bonded article in accordance with the standard and familiar practice in the art, but so carrying out the cooling stage of the process as to cool the wheel through the bond solidifying period so that the central zone is maintained at a lower temperature than the periphery, then solidifying the mass and eliminating the temperature difference between the inner and outer zones of the solidified body to thereby impose a compressional stress on the bond at the inner zone and a tensional strain in the outer peripheral zone when the wheel is at uniform room temperature. In other words, the temperature gradient between the inner and outer zones during the cooling will carry a negative sign so that cooling and solidification of the article will start first from the inner zone adjacent to the center, then move gradually outwardly until the plastic mass at the periphery will be the last to cool and become rigid. The real criterion is not how fast cooling may take place but how great the temperature difference may be between the inner and outer zones of the wheel in cooling through the annealing range of temperatures to room temperature. It is to be understood that the zones herein referred to are circular and the principal stresses under consideration therein are tangential stresses.

One method of producing a grinding wheel, in which the previous condition of tensile strain will not be present in the inner central zone, but having instead a required condition of strain impressed in that particular zone to produce a greater strength than normally obtained by cooling the wheel in accordance with the standard practice may be carried out as follows: Granular abrasive material, such as crystalline alumina or silicon carbide granules, may be mixed with an appropriate vitrifiable bond mixture consisting of fusible clays, feldspars, fluxes and the like. The bond composition for each abrasive will be determined by the required grinding characteristics of the wheel, and may be readily selected by one skilled in the ceramic art. It is preferred, however, that the bond be of a composition which will have substantially the same coefficient of expansion as the abrasive grains throughout a long range of temperature change below the temperature of softening or annealing of the matured bond, thereby minimizing the formation of internal contact strains at the surface of the grains as the body cools. In that case, the bond composition may be made up in accordance with the invention described in the patent to Saunders et al. No. 1,829,761 of November 3, 1931.

As a specific example of a grinding wheel made with this bond, I may employ crystalline alumina grains in suitable grit sizes which have an approximate chemical analysis of alumina 95.24%, ferric oxide 0.74%, silica 0.93%, and titania 3.09%. The bond mixture employed may be of the following composition:

	Per cent by weight
Silicon dioxide	55.0
Aluminum oxide	11.4
Ferric oxide	4.3
Magnesium oxide	2.8
Calcium oxide	5.9
Sodium oxide	6.0
Potassium oxide	2.6
Titanium oxide	0.7
Boron oxide	11.3
Total	100.0

A glass made up of this composition is found

to have a linear coefficient of expansion of about 72 x 10^{-7} which, below about 550° C., remains substantially the same as the average coefficient of expansion of the crystalline alumina abrasive grains.

As a specific example, I may make a wheel 24" x 2" x 3", using the above bond and crystalline alumina grains of a grit size which will just pass through a screen of 30 meshes to the linear inch. Various grades of hardness or structure of grinding wheel may be made with this bond, such as by using 2¾ ounces of the bond per pound of abrasive grains, with suitable additions of water or a solution of a temporary binding material, such as dextrine, to render the mass workable during the mixing operation. The mixture may be then shaped in a mold and pressed to produce a desired volume structure. The thus shaped article is then dried preparatory for the firing operation.

In carrying out the firing process, various types of furnace constructions may be employed, provided there are means for controlling the heat conditions which will afford a close regulation of the furnace temperature. The drawing illustrates the preferred manner of carrying out the firing operation which has been found to be satisfactory. The structure comprises an electric resistance furnace in which the grinding wheels may be fired individually under predetermined and controlled heat conditions. Referring to the drawing, the furnace, as shown diagrammatically in Fig. 1, may be of the usual form well known in the art comprising the walls 10 of suitable refractory or heat insulating material which form a heating chamber 12 having a dome shaped roof. The inner walls of the chamber 12 are covered with a lining 13 constructed of a suitable refractory material, such as bricks made of silicon carbide, fused alumina, silica or other well known refractory material.

Two sets of superimposed rows of non-metallic resistance heating elements 15, preferably in the form of self-sustaining, molded and heat hardened rod-shaped bodies of silicon carbide, are shown as disposed in the furnace chamber 12 and extending therethrough, with the terminals of the elements projecting into suitable apertures formed through side walls of the refractory chamber 12 and the outer covering wall 10. The heating elements are supported by and electrically connected through the water cooled terminals 18, in accordance with the usual manner. The heat conditions within the furnace chamber after the firing operation may be controlled by means of suitable air ducts 19 and 20 and dampers 21 and 22 respectively, by which either cool air from the atmosphere may be admitted to the heating chamber 12 or an exhaustion of the hot furnace gases may be effected.

In the process of firing grinding wheels in accordance with this invention, a grinding wheel 25, which has been previously molded to the desired size and shape, is laid on a circular batt 26 of refractory material having a diameter greater than the diameter of the wheel, with a central aperture 27 of slightly smaller diameter than the wheel hole 28, the wheel being supported from the floor of the furnace chamber 12 and between the rows of heating elements 15 by means of stands 29 of suitable refractory material, such as ceramic bonded silicon carbide or crystalline alumina or a high burned fire clay product. A ring 30 of similar refractory material, which may be formed in jointed sections, is then placed in close proximity to the periphery of the wheel 25, the ring resting on the outer edge of the batt 26 and being of sufficient height to reach the level of the top face of the wheel. A second circular batt 31 of like refractory material having the same outside diameter as the supporting batt 26, but with a central aperture 32 having an inner diameter sufficient to expose a substantial portion of the upper surface of the wheel material, such as the first third of the radial distance from the hole, is then laid on the top of the wheel and the ring 30. Upon the top of the upper batt 31 is placed an insulating covering 33 of a clay which will not fuse or soften materially at the temperature of firing, such as kaolin grog and fire clay, which is built up around the top surface of the batt in the form of a ring of substantial thickness at the periphery and tapering off gradually towards the center until it has little thickness at the edge of the hole of the batt 31. The joints between the batts 26 and 31 and the ring 30, as well as the cracks between the various sections of the ring, are then filled with the standard luting of plastic clay or other cementitious refractory substance. If desired, the refractory ring 30 may be set to leave a slight space between the peripheral face of the wheel, in which case the intervening space therebetween will also be filled with the plastic clay material, such as a plastic clay grog. The wheel thus constructed is now completely encased within a refractory casing which serves to insulate the peripheral portion of the wheel and thereby retard the dissipation of heat too rapidly at the outer or peripheral zone of the wheel prior to solidification of the wheel material at the interior zone during the annealing and cooling stages. The wheel may then be fired by passing an electric current through the heating elements 15 for such length of time and at a suitable rate of temperature rise as to bring the furnace and the wheel to a temperature of about 1150° C., for the bond set forth in the above example, or to such a temperature which, according to the standard practice in the ceramic art, will vitrify the particular bonding material employed. The wheel is then allowed to "soak" at this temperature for a suitable length of time, after which the furnace and the fired wheel are cooled so as to set up a temperature difference between the central and peripheral portions which is proportional to the degree of compressional strain desired in the central portion of the wheel, during which process the central portion is kept cooler than the periphery. The cooling process further continues with the maintenance of this same temperature difference between the zones until the temperature of the mass reaches 450° C., where the bond setting process is complete and the body becomes solid and rigid. Further cooling takes place between the temperature limits at which the bond is in a rigid condition until the mass is at room temperature, during which stage the temperature differential set up between the inner and outer portions has been eliminated and a compressional stress is produced in the central portion of the wheel which is relatively proportional to temperature difference which existed in the wheel.

In order to apply a reverse or compressional tangential strain to the inner zone of the wheel, the material at the central zone adjacent to the hole and exposed by the large central opening in the batt 31 is caused to cool more rapidly than that at the periphery, which is insulated dur-

ing this cooling process by the refractory coating 33, in order to keep the softened wheel material there covered to prevent it from losing its heat too quickly and, in addition, keep the heated peripheral portion out of contact with the atmosphere to prevent rapid absorption and transfer of the heat thereto. During the cooling of the wheel through the critical annealing range, the temperature of the furnace atmosphere is controlled, as by means of the dampers 21 and 22, in such a manner as to maintain a temperature differential of a negative character. That is, a condition of cooling is maintained in the furnace, whereby the wheel material adjacent to the central zone is maintained at a lower temperature than that near to the periphery. For the particular example, a temperature difference of −15° C., as measured at two points along the wheel radius, and preferably located at 0.4 and 0.875 the distance from the center, is found to be suitable for the purpose, but this temperature difference may be suitably varied, as determined by the desired magnitude of compressional stress to be obtained, as well as the nature and size of the wheel being fired. However, the amount of compressional stress induced therein should not be made great enough to rupture the wheel.

It will be apparent, therefore, that the heat from the central zone of the wheel will dissipate more rapidly to the surrounding atmosphere than will that of the outer zone, while the wheel is cooling in the furnace. Hence, due to the negative character of the temperature gradient which exists between the central zone and the periphery of the wheel, the bond mixture adjacent to the hole will be subjected to the influences of compressional stress.

In the modification shown in Fig. 2, the pipes 35 and 36 are shown communicating with the ducts 19 and 20 by which air may be circulated directly through the wheel hole after the firing operation in order to cool off the material about the central hole at a faster rate than that at the outer peripheral zone and so produce a greater temperature difference between these zones thereby inducing a reverse or compressional strain in the material of the inner zone. In this case, the firing process may be carried out with or without the refractory covering 33, depending on the temperature gradient desired between the respective zones. Various other arrangements of structure and modifications of the method may be made within the scope of this invention. For example, a vitrified wheel which has been made in accordance with the prior practice employed in the art may be refired to a temperature of approximately 800° C., more or less, and then cooled in the manner as above explained, as to induce a compressional strain in the material adjacent to the central hole.

It will be understood that the compressional stress produced in the wheel exists as a tangential force at the hole of the wheel and is opposite in direction to the tangential forces set up by rotation and frictional heat at the periphery of the wheel. Hence, the reverse strain and its attendant stress, as thus imposed on the inner zone, in effect serves to strengthen the wheel adjacent to the hole or in the central portion where breakage normally starts. This compressional stress set up by the reverse strain must be neutralized by centrifugal force or a heat differential stress before the normal strength of the vitrified bonded structure needs to act in resisting these major destructive forces.

By proper control of the cooling conditions, one may vary this compressional force and impose any desired amount of reverse strain on the wheel bond, within the limits of the elasticity and strength of the outer zone material. A wheel made in accordance with the above procedure and formula and subjected to a differential cooling temperature of 15° C., between the outer and inner zones, was found to withstand a speed of 23,000 s. f. p. m. without breakage. As compared with this, a grinding wheel of the same type made in accordance with standard procedure is ordinarily speed tested at the maximum speed of 9,000 s. f. p. m., and will ordinarily break at a speed of 16,500 s. f. p. m., which is far below that at which a wheel carrying this reverse strain will rotate safely during a grinding operation.

Having thus described the invention, what is claimed as new and desired to secure by Letters Patent is:

1. A grinding wheel comprising a rigid body composed of bonded abrasive grains in which the peripheral portion of the wheel is shrunk upon and applies a compressional force to the material of the central portion of the wheel independently of any mechanical device, said force acting in a direction opposite to and tending to oppose the normal stress induced in the wheel by centrifugal force and differential heat strains arising during rotation and use thereof.

2. A grinding wheel comprising a rigid body of abrasive grains united together into an integral mass by a bond in which the wheel material in the portion adjacent to the center, independently of any mechanical device, is under a reverse strain set up therein by a differential cooling of the peripheral and central portions of the wheel which applies a compressional stress to the central portion and resists the action of the normal stress induced therein by centrifugal force and differential heat strains arising during rotation and use of the wheel.

3. The method of making an abrasive article composed of bonded abrasive grains comprising the steps of mixing abrasive grains with the raw bond, heating the molded mass to a temperature at which the bond is capable of adhering to and uniting the abrasive grains, and thereafter setting the bond at the central portion of the body to a solid condition before the outer portion is set, so that the subsequent solidification of the outer portion during cooling imposes a compressional stress within the central portion of the bonded wheel structure.

4. The method of making a grinding wheel comprising the steps of molding an abrasive body made of a mixture of abrasive grains and a vitrifiable ceramic bonding material, firing the molded mass to a temperature at which the ceramic material becomes plastic, and thereafter cooling the wheel mass through the annealing range to solidification while controlling the respective temperatures of the central and peripheral portions of the wheel and thereby lessening the tensional stress in the central portion of the wheel and obtaining a required condition of strain which serves to provide a greater wheel strength than that normally obtained by cooling a wheel mass to room temperature from the periphery inwardly.

5. The method of making abrasive articles containing granular abrasive material and a vitrifiable bond which comprises firing the mixture in the raw condition to mature the bond, and thereafter cooling the bond constituents to solidifica-

tion and causing the material at the interior portion of the article to be cooled more rapidly than the outer zone and to be put under a compressional stress by contraction of the outer zone which serves to strengthen the wheel.

6. The method of making a grinding wheel of abrasive grains united by a vitrified bonded ceramic material comprising the steps of shaping a wheel body provided with a central hole from a mixture of abrasive grains and of a plastic vitrifiable ceramic bond, firing it under conditions which serve to mature the ceramic bond to a plastic condition capable of adhering to and uniting the abrasive grains, and thereafter cooling and solidifying the central portion of the wheel before the outer portion so that the subsequent solidification and contraction during cooling of the outer portion imposes a compressional stress within the bonded wheel structure adjacent to its hole.

7. The method of making an abrasive article composed of abrasive grains united by a vitrifiable ceramic material comprising the steps of mixing abrasive grains with a ceramic bond, firing a mass shaped from such a mixture in the raw condition to soften and mature the bond, and thereafter annealing the plastic mass by cooling it through that range of temperatures at which the bond solidifies and maintaining the central portion of the wheel sufficiently cooler than the outer portion adjacent to the periphery throughout an extensive range of temperature at the time of bond solidification so that the tendency for the material at the outer portion to contract upon solidifying and cooling will impose a compressional stress in the central solidified portion, which serves to strengthen the wheel and makes it more resistant to rupture by differential heat and operating stresses arising during a grinding operation.

8. The method of making a grinding wheel containing abrasive grains bonded by a vitrifiable ceramic material which comprises the steps of shaping a mixture of abrasive grains and ceramic bond, applying a suitable heat insulating covering on the top of the unfired shaped article near the periphery but exposing the central portion of the wheel body, so as to render the mass at the outer portion less heat conductive than the central zone, firing the covered article to soften and mature the bond, and cooling the plastic article while thus protected through that range of temperature at which the bond solidifies, and thus maintaining the central portion of the wheel sufficiently cooler than the outer zone throughout an extensive range of temperature at the time of bond solidification so that the contraction of the outer zone material upon solidifying and cooling will impose a compressional stress on said inner zone and so serve to strengthen the wheel and render it more resistant to rupture during a grinding operation.

9. The method of making a grinding wheel comprising the steps of firing a previously molded and finally matured vitrified grinding body composed of abrasive grains bonded by a vitrified ceramic material to a temperature at which the ceramic bond becomes plastic, and thereafter cooling the resoftened wheel mass to solidification from the center outwardly toward its periphery to impart to the material at the central portion of the wheel a compressional force which acts radially inwardly and serves to oppose and resist the normal tensional stresses induced in said portion during rotation and use of the body.

10. A grinding wheel comprising a rigid body of abrasive grains united together into an integral mass by a bond of vitrified ceramic material in which the wheel material in the portion adjacent to the center, independently of any mechanical device, is under a reverse strain set up therein by a differential cooling of the peripheral and central portions of the wheel which applies a compressional stress to the central portion and resists the action of the normal stress induced therein by centrifugal force and differential heat strains arising during rotation and use of the wheel.

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