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**Continuation-in-part of application Ser. No. 634,622, Apr. 28, 1967, now abandoned.**

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[54] **THERMOSET-RESIN IMPREGNATED HIGH-SPEED VITREOUS GRINDING WHEEL**  
**6 Claims, 6 Drawing Figs.**

[52] U.S. Cl. .... **51/295,**  
 51/298, 51/308, 51/309

[51] Int. Cl. .... **B24d 5/02,**  
 C08g 17/14

[50] Field of Search ..... **51/295,**  
 296, 298, 307, 308, 309

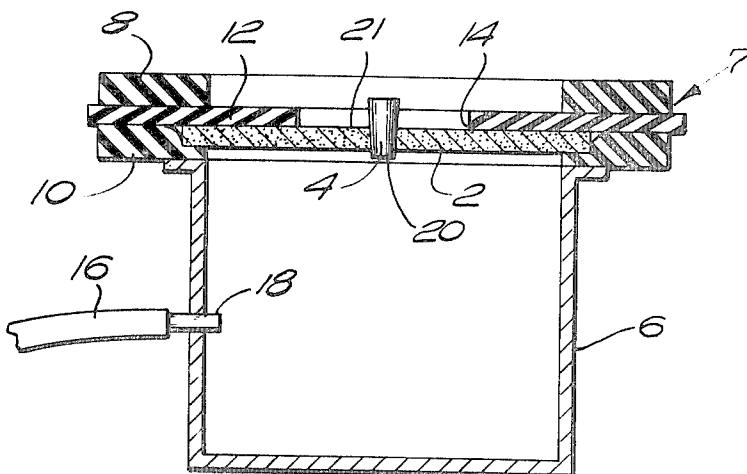
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**ABSTRACT:** A porous vitreous bonded high-speed abrasive grinding wheel in which between about 95 percent and 100 percent of the pore volume of either the annular portion of the wheel adjacent to the wheel hole or the entire wheel is impregnated with either a thermoset epoxy resin which is a copolymer of a liquid epoxy prepolymer and an amine or organic acid anhydride, or, a thermoset unsaturated polyester resin which is a copolymer of a polyester prepolymer containing ethylenic unsaturation and an ethylenically unsaturated reactive diluent like styrene, vinyl acetate, methyl methacrylate, and the like.

The wheel is preferably impregnated by applying the mixture of liquid prepolymer and hardener (cross-linking agent) to one side of the wheel over the area to be impregnated, preferably with a vacuum applied to one side of the wheel to draw the liquid prepolymer-hardener mixture into the pores of the wheel. Copolymerization (cross-linking) of the prepolymer-hardener mixture occurs in situ in the pores.

The cross-linked epoxy or unsaturated polyester resin may form an internal bushing of solid resin with substantial radial impregnation into the wheel. In such cases, the prepolymer-hardener mixture is introduced into the wheel hole around an arbor with a mold plate over both sides of the hole and extending radially along the wheel surfaces to the extent of desired penetration.



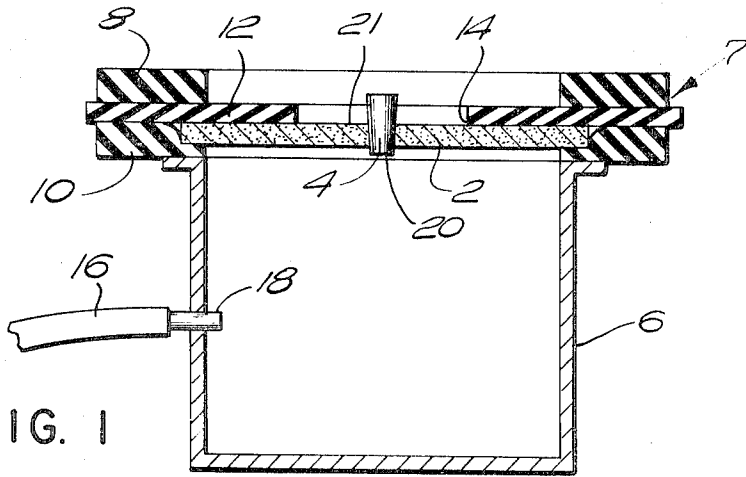


FIG. 1

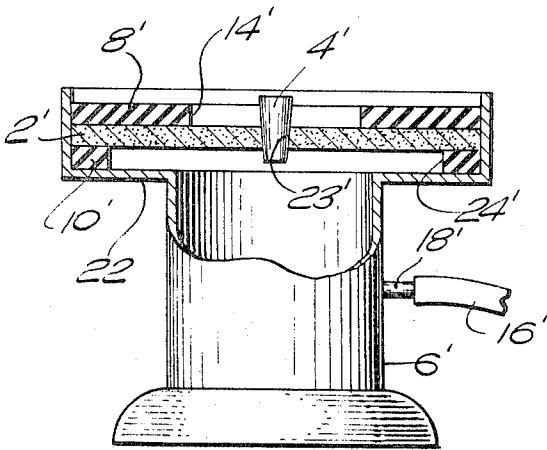


FIG. 2

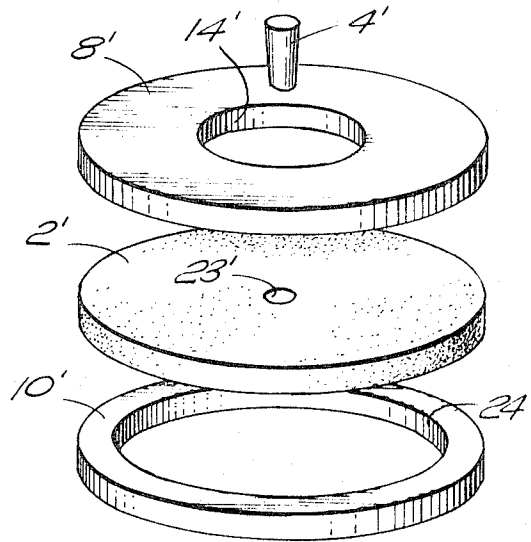


FIG. 3

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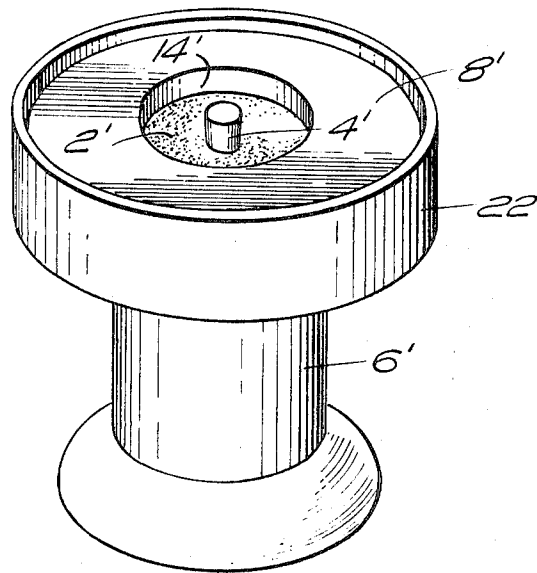


FIG. 4

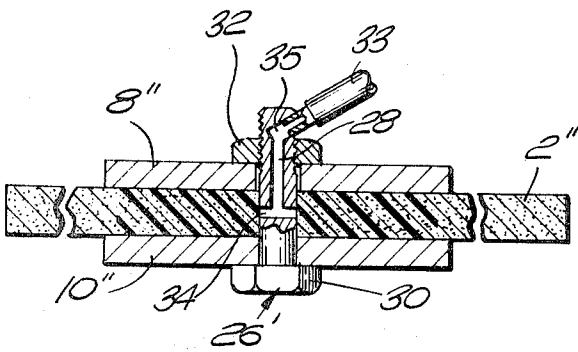


FIG. 5

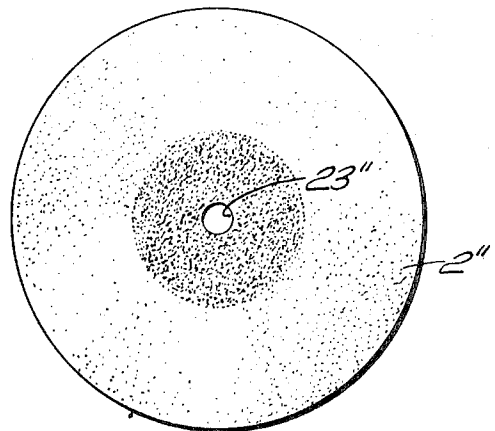


FIG. 6

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## THERMOSET-RESIN IMPREGNATED HIGH-SPEED VITREOUS GRINDING WHEEL

This is a continuation-in-part of application Ser. No. 634,622 filed Apr. 28, 1967, now abandoned.

### BACKGROUND OF THE INVENTION

Vitrified or vitreous (ceramic) bonded abrasive grinding wheels and other abrasive products are made up of particles of an abrasive substance such as alumina in a continuous, vitreous, glassy or ceramic matrix. Such vitrified bonded abrasive wheels are very durable, provide good grinding action and are noted for their ability to maintain the shape of the grinding face. These products are usually porous to some degree, the porosity varying considerably, depending on grain size, the amount and kind of bonding material used, the method of manufacture, etc.

Attempts have been made to increase the strength, toughness and shock or impact resistance of vitreous bonded grinding wheels, to thereby increase the maximum operating speed at which they can be operated as well as the maximum compression force and shock to which they can be subjected, by impregnating the pores of the wheel with a thermoplastic or thermosetting resin. Various resins and similar substances have been suggested, including phenolic resins, waxes, benzofuran resins, shellac, furfuryl resins, rubber, cellulose resins, asphalt, gums, glue, etc. None of these have achieved commercial success. It is believed that the reasons for this are as follows: (1) it is difficult to retain a sufficient amount of the solid resin or other material in the pores (sufficient loading) to add enough strength and resistance to shock to warrant the expense of the operation. The more porous the wheel, the weaker it is. Adequate resin loading and retention is especially difficult with ceramic grinding wheels having relatively high porosity (e.g. 25-50 percent porosity by volume), relatively large grit sizes (e.g. 24-60) and relatively small ceramic content (e.g. 3-18 percent by volume). The larger the grit size and smaller the ceramic content, the greater the pore volume and pore diameter;

(2) those resinous materials, particularly thermoplastics, which may be capable of adequate pore loading and retention are either too weak or too brittle or too soft to provide sufficient added strength and resistance to shock, or have flow characteristics (too flowable) or melting points (in the case of thermoplastic materials) which render them unsuitable. If the material tends to flow or break up at high speed operation and under shock or compression, it may do more harm than good.

### SUMMARY OF THE INVENTION

It has been discovered that the strength, impact resistance and resistance to compressive and tensile centrifugal forces can be greatly increased by impregnating the pores of ceramic bonded abrasive grinding wheels, particularly the annular portion adjacent the wheel hole, with (1) a thermoset, cross-linked epoxy resin, namely a cross-linked copolymer of (a) a liquid, epoxy prepolymer, such as a prepolymer of epichlorohydrin and a bisphenol, and (b) a cross-linking compound or hardener of the group consisting of an organic polyamine and an organic acid anhydride or, (2) a thermoset unsaturated polyester resin, i.e. the copolymer of a liquid mixture of an unsaturated polyester prepolymer and a reactive unsaturated diluent e.g. the copolymerization of the condensation reaction product of an unsaturated dibasic acid and a saturated glycol with an unsaturated vinyl-type monomer, the free radical copolymerization reaction being initiated by such free radical initiators as organic peroxides and azo compounds. As a consequence, the wheels can withstand extremely high rotational speeds and impact as compared to known ceramic bonded grinding wheels and hence are extremely well suited for high-speed grinding.

The pores are impregnated with a mixture of the prepolymer and the cross-linking compound and copolymerization (curing) occurs in situ within the pores at room temperature, i.e. without adding heat except for the ex-

othermic heat of reaction. Curing at room temperature is preferred to reduce foaming or bubbling and seepage, although after curing has been completed at room temperature to a point at which the resin has solidified and hardened, it may be desirable to insure complete curing by a post cure baking operation. However, in certain cases, elevated temperature post curing may cause uneven expansion and contraction of the resin and glassy matrix, especially when relatively high temperatures are used. Post curing temperatures, when used, should not exceed about 225° C. and more preferably should not exceed about 100° C.

Surprisingly enough, it has been discovered that by impregnation with the aforesaid prepolymers and cross-linking compounds with in situ curing, between 95 to 100 percent resin loading and retention of the pore volume treated may be achieved, i.e. between 95 and 100 percent of the pore volume treated can be filled with and retains the solid cross-linked copolymer, even with pore volumes between 25 and 52 percent of the total wheel volume (exclusive of the wheel hole), so that the ceramic wheel becomes substantially nonporous, i.e. it has a pore volume of from 0 percent to 5 percent. This combined with the fact that the solid cross-linked copolymer is itself extremely strong, hard, tough, and resistant to shock and does not flow significantly even at extremely high wheel speeds and at high temperatures or when subjected to substantial impact forces, provides a ceramic grinding wheel which can be subjected to higher speeds and greater compression and impact forces than ceramic grinding wheels known heretofore. The molecular structure of the cured epoxy or unsaturated polyester resins is such that although they are highly resistant to flow and thermal effects, they are not brittle. This may be due to the spacing of the molecular chains and the relatively low density of cross-links per unit area of cross-linked copolymer, i.e. the number of cross-links per unit area of resin.

Preferably, only the portion of the wheel adjacent to the wheel hole is impregnated from about one third to one half the radial distance from the hole wall to the wheel periphery with the peripheral grinding portion remaining untreated. In this way, the grinding properties of the wheel remain unchanged. However, the entire wheel or any particular portion may be so treated and, in some cases, the impregnated epoxy or unsaturated polyester resin provides grinding advantages.

Preferably, the liquid mixture of prepolymer and cross-linking compound is applied to one side of the portion of the wheel to be treated and is drawn into the pores either by gravity but more preferably by applying a vacuum to the other side of such wheel portion, an arbor or plug being located in the wheel hole. The vacuum is sufficient only to pull the prepolymer-cross-linking compound mix into the pores and the magnitude of vacuum required to do this depends on the porosity of the wheel and the viscosity of the mix. Generally the vacuum may vary between about 10 and 300 or 400 mm. Hg with a pull of between 750 mm. Hg and 360 or 460 mm. Hg based on atmospheric pressure on the side of the wheel to which the mix is applied. Of course, if a positive pressure is applied to the aforesaid side of the wheel, the vacuum can be omitted.

Preferred curing conditions for the impregnated epoxy of unsaturated polyester resin are those which limit the exotherm and avoid excessive foaming or bubbling. This can be accomplished by selecting curing agents which are not too rapid in action or by the use of known polymerization inhibitors such as water, in the case of the epoxy resins, which may be mixed with the prepolymer-cross-linking compound mix. Not only does a high exotherm, caused by too rapid polymerization, cause foaming but also it may cause uneven and harmful expansion and contraction of the impregnant resin and the ceramic matrix. Generally, the more rapid the curing time, the better the results, so long as it is not so rapid as to present difficulties in handling the liquid mix between mixing and application to the wheel or to raise the exotherm too high or cause excessive foaming.

An inner solid cross-linked epoxy or unsaturated polyester resin bushing for the grinding wheel may be provided with radial penetration into a substantial portion of the ceramic wheel by starting with an oversized wheel hole and using an arbor having a diameter equal to that desired for the finished wheel hole but smaller than the diameter of the hole of the untreated wheel. When this is done, mold plates are located above and below the wheel hole and extend radially along the opposite sides of the wheel a distance equal to the desired penetration.

Impregnation of the press of the wheel portion adjacent the hole, with or without an inner solid bushing portion, can be achieved by use of a hollow arbor, located in the wheel hole, having a series of radial holes spaced around the circumference thereof and with the aforesaid plates on either side of the hole, whereby the liquid prepolymer-cross-linking compound mix is introduced into the hollow arbor and flowed radially through the holes into the pores of the wall of the wheel hole. It has been found that with the aforesaid prepolymer and cross-linking compound, excellent radial penetration, with or without a solid resin inner bushing, can be achieved without the use of high pressures as are used in injection molding.

Ceramic grinding wheels have in the past been bushed by (1) pouring molten lead into the wheel hole around a solid arbor and allowing it to solidify and (2) injection molding a hot thermoplastic material into the wheel hole around a solid arbor and cooling to solidify the plastic and form a solid plastic bushing. The first method is costly while the second method is unsatisfactory because the high injection pressures may break the weak abrasive structure and because high shrinkage of thermoplastic resins causes problems in maintaining desired high hole tolerances. By the use of the aforesaid liquid mix of epoxy or unsaturated polyester prepolymer and cross-linking compound in accordance with the invention, no substantial pressure need be exerted at the hole of the wheel and shrinkage of the solid resin material is not sufficient to cause trouble with maintaining hole tolerance dimensions. Also a stronger product can be achieved in accordance with the present invention by controlling the process so that the resin, in addition to forming a solid inner bushing, also fills the pores of a substantial annular portion of the wheel structure adjacent to the hole.

It is indeed surprising that with the use of the epoxy or unsaturated polyester prepolymer and cross-linking compound of the present invention, between 95 and 1100 percent resin loading and resin retention in the pores can be achieved with pore volumes as high as 52 percent, since with other thermosetting resins, such as available phenol formaldehyde systems, only a fraction of the pore volume retains the solid resin. This is undoubtedly one of the reasons that the ceramic impregnated wheel of the invention has much greater strength than a ceramic wheel impregnated with phenol resins and will withstand much greater speeds and compression forces.

Another reason for the increased resin loading and retention and also for the greater strength of the wheels of the present invention may be that the epoxy resin or unsaturated polyester becomes strongly bonded to the ceramic matrix through the highly polar nature of the cross-linked polymers; the adhesion characteristics of epoxy and polyester resin are well known.

Another reason for the increased resin loading and retention and also for the greater strength of the wheels of the present invention is that substantially no volatile reaction products are formed during the in situ curing so that no volatile matter is evolved during curing of the prepolymer with the cross-linking agent, whereas with phenolic resins substantial volatile matter is evolved.

It is also believed that another reason for the higher resin loading and retention of the pores which is achieved, aside from the lack of volatile matter given off and the adhesive bonding with the ceramic through the polymer's highly polar groups, is the peculiar physical and chemical properties, in-

cluding curing characteristics, of the prepolymer-cross-linking compounds, e.g. the changing viscosity and exothermal heat effects during curing from the time the prepolymer and cross-linking compound are mixed and applied to the wheel to the finally cured stage, as well as the speed of curing.

Epoxy resins have been suggested for use as bonding agents in place of ceramic in plastic bonded grinding wheels made by centrifugal molding. Also copolymers of unsaturated monomers with unsaturated esters of alcohols and polybasic acid prepolymers have been used as bonding agents and to impregnate plastic bonded grinding wheels. However, such wheels do not have the grinding characteristics of the ceramic wheels of the present invention.

The hardened impregnated epoxy of unsaturated polyester resin forms an essentially continuous phase in the grinding wheels of the invention.

Grinding aids may be advantageously incorporated into the resin phase either chemically as part of the resin bond or physically as a filler. For example, where an aliphatic polyamine curing agent is used to cure an epoxy prepolymer, the aliphatic group may contain a sulfur atom to provide the group -C-S-C-. Also, polysulfide compounds or elemental sulfur or halogen compounds, such as cryolite, can be incorporated into the prepolymer-cross-linking compound mix prior to impregnation, such compounds being present as a filler in the cured resin phase. Iron sulfide, potassium fluoroborate, vinylidene chloride, and other conventional fillers can be employed.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view in cross section of an apparatus for impregnating a ceramic bonded abrasive grinding wheel according to the invention by impregnating from one side of the wheel and using a vacuum on the other side.

FIG. 2 is a cutaway view of another apparatus for impregnating a ceramic bonded abrasive grinding wheel by impregnating from one side of the wheel and using a vacuum on the other side according to the invention.

FIG. 3 is an exploded view of certain parts of the apparatus of FIG. 2.

FIG. 4 is a view in perspective of the apparatus of FIG. 2.

FIG. 5 is a cross-sectional view of yet another apparatus for impregnating a ceramic grinding wheel in accordance with the invention by radial impregnation. FIG. 6 is a top view in plan of the impregnated grinding wheel of FIG. 5.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS FOR MAKING THE ABRASIVE PRODUCTS OF THE INVENTION AND FOR CARRYING OUT THE METHODS OF THE INVENTION

Referring to FIG. 1, the untreated ceramic bonded abrasive grinding wheel 2, with its hole plugged by a rubber plug or stopper 4, is held over the vacuum chamber 6 by means of an annular rubber mold 7. The periphery of the wheel is located between the two halves 8 and 10 of the mold 7 and has a ¼-inch thick, circular rubber sheet 12 located over the top surface or side thereof. The peripheral portions of the rubber sheet are clamped in position on the upper surface of the wheel 2, between the two halves of the mold and such sheet has a central hole 14 having a diameter greater than that of the wheel hole 20 and equal to the area of impregnation. Thus, the portion 21 of the top of the wheel 2 adjacent the wheel hole is exposed. A vacuum is provided in the vacuum chamber by means of a vacuum hose 16, plug 18 and a vacuum pump not shown.

A mixture of the liquid prepolymer and the cross-linking compound is poured onto the exposed top area 21 of the grinding wheel and the vacuum in chamber 6 draws the mixture into the pores of the portion of the grinding wheel adjacent the wheel hole below area 21.

In FIGS. 2-4, 6' represents the vacuum chamber having a cup-shaped portion 22 on the top thereof for receiving a lower

removable rubber mold plate 10', the grinding wheel 2' and an upper removable rubber mold plate 8' with an arbor or plug 4' extending through the center hole 14' in plate 8', the center hole 23' in the grinding wheel 2' and the center hole 24' in the lower plate. The hole in upper plate 8' is larger than the wheel hole to expose an area of the upper surface of the wheel adjacent to the wheel hole corresponding to the area to be impregnated. The hole 24' in the lower plate 10' is substantially larger than the hole in the upper plate. Plate 10' corresponds to mold half 10 in FIG. 1. The vacuum hose 16' and plug 18' connects with the vacuum pump not shown. In this construction, the rubber sheet is omitted and the upper mold plate is used to define the area of the wheel to be impregnated. The prepolymer-cross-linking compound mix is poured into the hole 14' of the upper mold plate 8' onto the exposed area of the wheel and is drawn into the pores of the wheel by the vacuum in chamber 6'.

In FIGS. 5 and 6, a bolt 26', having a center axial passage 28, fits snugly within the hole of the grinding wheel 2' with a pair of mold plates 8'' and 10'' on either side of the center portion of the wheel, as shown. The assembly is held together by means of enlarged bolt head 30 and nut 32. The lower end of axial passage 28 communicates with a plurality of radially extending circumferentially spaced holes or slots 34. The diameter of the seal plates 8'' and 10'' corresponds to the diameter of the area to be impregnated adjacent the wheel hole. The liquid mix of prepolymer and cross-linking curing compound is directed from a nozzle 33 axially through the passage 28 and thence radially through the radial passages 34 into the pores of the portion of the wheel adjacent the wheel hole. The seal plates insure the aforesaid radial flow of mix into the pores to a radial distance corresponding to the radial distance of the seal plates. Very little pressure, e.g. 10 p.s.i., is required to achieve good penetration. Such pressure is far below injection molding pressures and is too low to cause any damage to the ceramic matrix. By placing the assembly in a vacuum chamber, the vacuum will pull the liquid mix into the wheel pores with no positive pressure. By making the bolt of smaller diameter than the wheel hole to provide a space between the bolt periphery and the wall of the wheel hole, a solid resin bushing can be obtained together with radial penetration into the wheel to provide a bushing made up of an inner epoxy resin and an adjacent resin impregnated wheel portion.

#### EXAMPLE I

Two ceramic bonded aluminum oxide grinding wheels were impregnated in an area 1½ inches (radial distance) around the hole. The size of the wheel was 7 inches (diameter) × ½ inch (hole size) × 1¼ inches (thickness). The pore volume or porosity was 47 percent, the grain size was 46 grit and the percent by volume of ceramic or glassy matrix was 4.6 percent. The wheel was placed in the apparatus shown in FIG. 1. The mold aperture (central hole in mold 7) was 6 inches with an outside mold diameter of 12 inches. The mold recess of 7 inches diameter by one-half inch in thickness. The soft rubber sheet 12 was 14 inches in diameter and 1¼ inches thick with an opening 2½ inches at the center.

50 grams of a liquid prepolymer of epichlorhydrin and Bisphenol A, having a viscosity of 4,000 c.p.s. at 23° C. (Brookfield viscometer) and an epoxy value of 0.39 Eq/100 g. and sold by Ciba Products Corporation under the name Araldite 502, was mixed with 3 grams of a liquid aliphatic polyamine hardener (cross-linking compound), sold under the name DP-112 by Ciba Products Corporation, and 14 drops of water (inhibitor). The mixture was poured on the portion of the grinding wheel exposed by the hole in the rubber sheet while maintaining a moderate vacuum in the vacuum chamber. The vacuum drew most of the liquid mix into the pores of the grinding wheel in 45 seconds, whereafter the vacuum was discontinued. The impregnated resin hardened in about 2 minutes at room temperature. About 95 percent of the

pore volume of the portion of the wheel treated, i.e. the portion of the wheel below the exposed area, was filled with solid epoxy resin.

The impregnated wheels are placed on a smooth rubber surface. A mixture of 25 grams of Araldite 502 epoxy resin prepolymer, 1.5 grams of Araldite Hardener, DP 112, and 15 grams of Cryolite powder were mixed and poured into the hole of each wheel around a cylindrical steel arbor centrally located in the hole and having a diameter of one-fourth inch. After approximately 1½ minutes at room temperature, the material had formed a solid epoxy resin bushing around the arbor.

Two more grinding wheels having the same construction were bushed with epoxy resin in the same manner as aforesaid without prior impregnation of the wheel.

Two more grinding wheels having the same construction were bushed using lead as the material poured into the wheel hole and without prior impregnation of the wheel with resin.

Speed tests to destruction were run on all these wheels. The speed of the wheel was increased until the wheel broke. The results were as follows:

	r.p.m. at Which Breakage Occurred	Average % Improvement
Standard Lead Bushing	10,000;9700	
Epoxy Resin Bushing Without Impregnation	11,200;11,900	18% over Lead
Epoxy Resin Bushing With Impregnation	13,600	39% Over Lead

#### EXAMPLE II

The ceramic bonded wheels in this example were 8×¾×1¼ inches and had a pore volume of 46.4 percent, a grain size of 60 grit (silicon carbide) and a percent volume of ceramic of 5.6 percent.

A mixture of 50 grams of Araldite 502 epoxy resin prepolymer, 3 grams of Araldite Hardener DP 112 and 0.8 grams of water were mixed and poured into the hole of each of two of the wheels around a steel arbor with the wheel being supported on a smooth rubber surface. After 5 minutes at room temperature, this material had formed a solid epoxy resin bushing around the arbor and had also penetrated approximately three-fourths inch radially into the wheel structure. Between 95 and 100 percent of the pore volume of the penetrated impregnated portion of the wheel was filled with the solid epoxy resin.

Two more wheels having the same construction were bushed in the same way using lead as the material.

These wheels were broken in the standard centrifugal test preferred to in example I:

	r.p.m.	Average % Improvement
Standard Lead Bushing	7,200,8,000	
Epoxy Resin Bushing	11,200	47% Over Lead

#### EXAMPLE III

The ceramic bonded grinding wheel of this example was 12×1×3 inches. The grain size (fused alumina) was 46 grit. The pore volume was 46 percent and the percent by volume of the ceramic matrix was 5.8. The wheel was cleaned with air to allow maximum penetration of the wheel pores. 2 pounds of a viscous liquid linear prepolymer of epichlorhydrin and Bisphenol A having a viscosity of between 12,000 and 19,000 c.p.s. at 25° C., an epoxy assay of 170 to 182 (grams per gram-mole epoxy i.e. approximately two epoxy groups per prepolymer molecule) and sold by the Union Carbide Corporation under the name ERL-3794, were mixed with 0.75 pound of a cyanoethylation product of an aliphatic amine, having the formula  $N \equiv CCH_2CH_2NRNCH_2CH_2C \equiv N$  (43-47

percent amine) and a viscosity of 90 to 125 c.p.s. at 25° C. and sold by the Union Carbide Corporation under the name ZYL-0803 as a hardener (cross-linking compound) for the ERL-3794 prepolymer. Likewise, one pound of ERL-3794 and 0.38 pound of ZYL-0803 were mixed in a separate contained container to form a second batch of prepolymer-hardener mix. Two batches were made to reduce the exotherm. The two mixes had a viscosity of between 800-1600 c.p.s. and were blended and quickly poured on the top surface of the grinding wheel set in aluminum foil in a cardboard retaining cylinder. Wheel and resin were put into a vacuum chamber at 28½ inches Hg at room temperature for 30 minutes with a maximum vacuum of 29 inches Hg attained for the last 20 minutes. Foaming was not excessive and consisted of continual release of fine bubbles which collected on the surface and coalesced into larger bubbles as the foaming slowed. The vacuum was removed and the surface of the resin was bubblefree. After 4 hours gelatin began to occur and the excess resin on the outside of the wheel was removed easily with a spatula. The exotherm which followed during the next hour did not exceed 50-55° C. (120-131°F.). The impregnated wheel remained at room temperature for 2½ days and was then post cured by baking for 24 hours as follows: 8 hours at 120° C.; 16 hours at 120° C. Essentially, 100 percent of the pore volume of the wheel was filled with the solid cross-linked epoxy resin.

Speed tests to destruction were run on the above wheel and an untreated wheel having the same construction. The tests were at room temperature and the wheels were dry.

	Surface speed per Minute At Which Wheel Was Destroyed
Standard untreated wheel	15,300
Epoxy resin impregnated wheel	26,000

Standard tests to determine the compressive strength of the wheels were carried out using blocks cut from each of the wheels and a 120,000 lb. Olsen testing machine, 120,000 lb. range, 050 inches per minute load rate. The blocks were 1×1 3/8 2 inches. A phenolic resin impregnated wheel had a compressive strength 7 percent greater than the untreated wheel and the epoxy resin impregnated wheel had a compressive strength 181 percent greater than the untreated wheel.

#### EXAMPLE IV

A wheel having the construction of example III was used in this example. Only the portion thereof adjacent the wheel hole was impregnated with epoxy resin in the apparatus shown in FIGS. 2 to 4. The zone of impregnation extended about one third the radial distance from the wall of the wheel hole to the periphery of the wheel. The vacuum was about 28 inches Hg. The same prepolymer-hardener mix was poured onto the exposed area of the wheel with curing occurring in situ in the wheel. Most of the mix had passed into the wheel within 30 minutes after which the wheel was removed and treated in the manner of example III. The impregnated portion of the wheel adjacent the hole formed a bushing and between 95 and 100 percent of the pores of such portion were filled with solid epoxy resin.

The relative improvement in the speed tests of the epoxy resin impregnated wheel over the untreated wheel compared to that in example III.

#### EXAMPLE V

Ceramic bonded aluminum oxide grinding wheel structures, in the form of 4×1½ inches rectangular bars, were completely impregnated with a mixture of an epoxy resin prepolymer and an aromatic amine hardener. The abrasive structure contained 46-grit aluminum oxide abrasive and had a volume composition of:

abrasive	48%
bond	8.5%
pores	43.5%

The resin-hardener mixture was comprised of 100 parts by weight of epoxy prepolymer Epon 828 and 20 parts by weight of aromatic amine hardener Z, both manufactured by the Shell Chemical Company.

Impregnation of two bars was accomplished by heating the resin-hardener mixture to about 50° C. and soaking of the bars in the hot mixture. The essentially completely impregnated bars were then heat treated 2 hours at 80° C. followed by 2 hours at 150° C. to cure the organic mixture.

The impregnated bars, along with two nonimpregnated bars of the same composition, was subjected to a flexural (cross-bending) test using 2-point loading, with the following results:

Impregnant	Ave. Modulus of Rupture in p.s.i.	Improvement
none	3060	
Epon 828 + hardener Z	3970	30%

#### EXAMPLE VI

Two ceramic bonded aluminum oxide grinding wheel structures of the same configuration and volume percent composition as those of example V were completely impregnated with a mixture of 99.5 parts of Marco X1095 unsaturated polyester resin containing styrene diluent, sold by the Marco Chemical Company; and 0.5 part of Cadox MDP, which is methyl ethyl ketone peroxide sold by the Cadet Chemical Corporation. The impregnation was carried out by allowing the unsaturated polyester-catalyst mixture to soak into the bars at atmospheric pressure. The impregnated bars were cured by allowing them to stand at room temperature for 48 hours followed by 96 hours at 50° C. and 47 hours at 110° C.

These impregnated bars, along with five nonimpregnated bars, were subjected to the same flexural test as was employed in example V, with the following results:

Impregnant	Ave. Modulus of Rupture in p.s.i.	Improvement
none	2653	
Marco X1095 + Cadox MDP	4345	64%

Other known cross-linking polyamine hardening agents for epoxy prepolymers, such as triethylene tetramine, can be used. Also other known organic anhydride hardeners for curing epoxy resins, such as phthalic and maleic anhydride, can be used. Where excessive foaming occurs in the initial in situ curing before hardening of the resin, it is preferred to either use a slower acting hardener or known inhibitors such as water to reduce the foaming and exotherm.

The viscosity of the prepolymer should not be so great that when it is mixed with the hardener and applied to the wheel, the viscosity of the mix is too great for easy penetration into the pores of the wheel. On the other hand, for optimum retention of resin in the pores the viscosity of the prepolymer should not be much less than about 500 centipoises at 25° C. Minimum and maximum viscosities will depend on the size and volume of the pores of the grinding wheel. The amount of liquid prepolymer-hardener mix used should be sufficient to form a volume of solid resin substantially in excess of the total pore volume of the portion of the wheel to be impregnated. The ratio of hardener to prepolymer will vary depending on the particular hardener and the particular prepolymer used. Such ratios are known.

Epoxy prepolymers other than those of Epichlorhydrin and Bisphenol, e.g. Bisphenol A and Bisphenol F, can be used so

long as they are liquid, prepolymers having at least two epoxy and/or hydroxy cross-linking sites, e.g. glycerol-based epoxy prepolymers (glycerol-epichlorhydrin resins), phenol formaldehyde-epichlorhydrin condensates, tetra kis (hydroxy phenol) alkane epoxy prepolymers, epoxidized polyolefins, etc.

The present invention is adapted for ceramic bonded abrasive grinding wheels having a pore volume of 25-52 percent, abrasive grain sizes between 24 grit and 320 grit and ceramic volume of between 3 percent and 18 percent.

When it is stated herein that the impregnated portion of the wheel surrounds and is adjacent to the wheel hole or the wall of the wheel hole, this includes a construction with no inner solid resin bushing as well as a construction with an inner solid resin bushing or any other kind of bushing, the term "wheel" being used to refer to the unbushed hole.

It should be pointed out here that in the preceding examples particular resin-hardener systems are employed which are subjected to specific cure cycles. Other epoxy or unsaturated polyester based resin-hardener systems may require different curing cycles in order to attain approximately optimum: (1) adhesion between the ceramic material and resin-hardener system; (2) shrinkage of the resin-hardener system. These things are well known to the skilled polymer chemist and constitute no part of the present invention.

It is however, not intended that the invention be limited by any theories, or to any products or examples, referred to above, but only to the products claimed below and their equivalents.

What is claimed is:

1. An improved ceramic bonded grinding wheel containing a hole therein, the pores of at least a predetermined portion of said wheel surrounding and adjacent to said hole being impregnated with a thermoset copolymer selected from the group consisting of an epoxy prepolymer having at least two epoxy and/or hydroxyl cross-linking sites copolymerized with an organic amine or an organic acid anhydride, and, an unsaturated polyester prepolymer copolymerized with an ethylenically unsaturated reactive diluent selected from the group consisting of styrene, vinyl toluene, methyl methacrylate and vinyl acetate, about 95 to 100 percent of the pore volume of said impregnated portion being filled with said thermoset copolymer.
2. The grinding wheel of claim 1 wherein only said portion is impregnated with said thermoset copolymer.
3. The grinding wheel of claim 1 wherein said epoxy prepolymer is the reaction product of epichlorohydrin and bisphenol.
4. The grinding wheel of claim 3 wherein said epoxy prepolymer is copolymerized with a cyanoethylated aliphatic amine.
5. The grinding wheel of claim 1 wherein said thermoset copolymer contains a grinding aid.
6. The grinding wheel of claim 1 wherein said hole therein contains a bushing of said thermoset copolymer which extends radially into said impregnated position.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,615,302 Dated October 26, 1971

Inventor(s) Robert A. Rowse et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 47, "1100" should read -- 100 -- . Column 7, lines 5 and 6, "contained" should be deleted. Column 9, line 2, cancel "based", second occurrence; line 15, "king", should read -- kind -- ; same line "wheel" should read -- wheel hole -- ; line 23, after "system" insert -- ; and, (3) tensile modulus of the resin-hardener system -- .

Signed and sealed this 14th day of November 1972.

(SEAL)  
Attest:

EDWARD M. FLETCHER, JR.  
Attesting Officer

ROBERT GOTTSCHALK  
Commissioner of Patents