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[54] **RESIN BONDED GRINDING WHEEL CONTAINING GAS-FILLED THERMOPLASTIC RESIN BEADS AND METHOD OF MAKING IT**

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[58] **Field of Search** 51/296, 298

[56] **References Cited**

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[57] **ABSTRACT**

An improved process is disclosed for making grinding wheels wherein a vinyl resin, such as polystyrene, or other suitable thermoplastic material is incorporated in the refractory composition with an epoxy binder or other binder which cures in the proper temperature range. The flat surface grinding wheels made in accordance with the invention and used on double-disc grinders function more effectively and facilitate rapid grinding and their useful life can be increased at least 3 or 4 times.

25 Claims, No Drawings

RESIN BONDED GRINDING WHEEL CONTAINING GAS-FILLED THERMOPLASTIC RESIN BEADS AND METHOD OF MAKING IT

REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of copending application Ser. No. 359,737, filed May 14, 1973, now abandoned, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to a resin bonded grinding wheel and more particularly to a surface grinding wheel containing a vinyl resin, such as polystyrene or other thermoplastic material which functions to keep the grinding surface clean and unclogged and to avoid overheating.

Very few grinding wheels have been found to be suitable for mass-production flat surface grinding of parts such as brake rotor discs used in automotive disc brakes because of the peculiar requirements of this type of precision grinding and the need to avoid glazing. Prior to the present invention, the most practical grinding wheels for this type of grinding were the so-called "resinoid" wheels using phenolic binders or the like. The standard double-disc grinding machines used, for example, to grind brake rotor discs employed such resinoid wheels in a soft grade with the expectation that they would wear out rapidly.

SUMMARY OF THE INVENTION

The present invention involves the discovery that certain types of flat surface grinding operations can be drastically improved, particularly the grinding of disc brake rotors and the like. The invention involves use of a refractory composition comprising at least 40 percent by volume of abrasive grains of aluminum oxide, silicon carbide or other suitable refractory material with a particle size preferably from about 30 mesh to about 100 mesh, a suitable synthetic resin binder, and a substantial amount of volume of polystyrene beads or beads of other thermoplastic resin that are capable of forming voids in the cured grinding wheel and that enable the worn grains to break away at the proper rate during the grinding operation. The amount by weight of refractory is at least several times the total weight of the resin binder and preferably in the range of from about 4 to about 8 times said total weight. The thermoplastic resin beads are substantially larger that the abrasive grains and have a particle size or diameter preferably from 0.05 to about 0.2 inch, a density preferably from about 1.5 to about 5 pounds per cubic foot, and a melting point preferably in the range of from about 350° to about 600°F.

The resin binder may be a conventional synthetic thermosetting resin binder, such as a diglycidyl ether of a bisphenol or other polyhydroxy phenol or other suitable epoxy resin having at least two epoxy groups, a phenol-formaldehyde binder, a urea-formaldehyde binder, a polyurethane binder, or other binder commonly used in grinding wheels. The preferred binders are epoxy resins, phenol-formaldehyde resins and polyurethanes, and best results are obtained with conventional epoxy resins, such as a diglycidyl ether of a bisphenol A.

It is found that a resin-bonded surface grinding wheel made according to the present invention and used in a conventional double-disc grinder for grinding brake rotor discs has a life at least several times than that of the resinoid wheels previously used for that purpose and effect grinding in a more efficient manner to produce a higher percentage of premium parts. It has also been found that the present invention makes it possible to make extremely soft grinding wheels which permit satisfactory operation of some grinding machines which would otherwise be out of service or unacceptable.

Thermoplastic beads function in a unique manner in a grinding wheel because of their ability to melt, soften or shrivel when heated. They are selected to provide proper resistance to melting during curing of the wheel so that they provide large voids in the wheel. If some of the beads have not shrunk or shriveled during the final curing of the wheel sufficiently to loosen the bond between the bead and the surrounding portions of the wheel, then they can soften and shrivel when heated during grinding. The result is that they usually break away and expose the void in the grinding surface well before the wheel wears down to half the depth of such void.

A glass, thermosetting or non-thermoplastic bead cannot function in this manner because it occupies space and wears away like the abrasive grains instead of melting or shriveling up. A hollow or porous non-thermoplastic material would, for example, become held in place by the binder like the abrasive grains and could not melt or shrink to break the bond. For this reason, non-thermoplastic beads are unsuitable for use in the present invention, except as a filler.

An object of the present invention is to provide a surface grinding wheel with an effective life at least several times that of previously known grinding wheels and which has less tendency to heat up during grinding.

A further object of the present invention is to provide a surface grinding wheel which has a more uniform grinding action and which will produce a higher percentage of premium parts than can be obtained with previously known grinding wheels.

These and other objects, uses and advantages of the present invention will become apparent to those skilled in the art from the following description and claims.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In carrying out the present invention, a surface grinding wheel is formed from a composition comprising from about 40 to about 75 percent by volume of finely divided abrasive refractory grains, from about 10 to about 40 percent by volume of hollow pieces or beads formed of polystyrene or other organic thermoplastic synthetic resin which melt when heated to a temperature in the range of from about 350° to about 600°F., and a thermosetting synthetic resin binder which can be hardened or cured at a temperature below 600°F. without substantially melting the thermoplastic beads, preferably at a temperature below 500°F. and below the melting point of the beads. In such composition the amount by weight of said refractory grains is generally from about 4 to about 8 times the total weight of said resin binder, which may be an epoxy resin, a urea-formaldehyde resin, a phenol-formaldehyde resin, or a polyurethane as described in more detail hereinafter.

The grinding wheels of the present invention preferably employ as the binder a diglycidyl ether of a bisphenol A, such as bisphenol acetone or its homologues or

closely related compounds. However, other epoxy resins can be used including glycidyl ethers of glycerol, glycidyl ethers of bisphenol F, glycidyl ethers of long chain bisphenols, and epoxylated novolacs. These other epoxy resins are well known in the art and are disclosed, for example, in "Handbook of Epoxy Resins" by Lee and Neville, Copyright 1967 by McGraw-Hill Book Company, Inc.

As used in the present specification, the term "epoxy resin" or "polyepoxide" refers to a resin having at least two alpha epoxy groups, and the term "epoxy group" means a 1,2-epoxy or alpha epoxy group.

The epoxy resins used in the grinding wheel compositions of this invention may be of various commercial types including Epon epoxy resins made by Shell Chemical Company (such as Epon 820, Epon 828 or Epon 834), Epi-Rez resins made by Jones-Dabney Company such as Epi-Rex 510, Araldite resins made by Ciba Co., Inc. such as Araldite 6010, or Bakelite epoxy resins made by Union Carbide Corp. such as ERL 2774 or the like. Other epoxy resins such as DER 331, DEN 431 or DEN 438 made by Dow Chemical Co. or other epoxy novolacs can also be used.

For example, epoxy resins suitable for use in grinding wheels made according to this invention can be made by reacting epichlorohydrin with (a) bisphenol acetone or other bisphenol A, (b) with bisphenol F, (c) with novolac resins having 3 to 6 or more phenol groups, (d) with mononuclear phenols, such as resorcinol, hydroquinone, catechol, or saligenin, (e) with binuclear phenols such as long chain bisphenols or halogenated bisphenols, such as tetrabromo-bisphenol A, (f) with tri- and tetranuclear phenols, (g) with various other polyhydroxy phenols, such as 4,4'-dihydroxy biphenyl, dihydroxyl diphenyl sulfone, or the like, or (h) with polyalcohols, such as ethylene glycol, glycerol, erythritol or 2,3-butanediol. Such epoxy resins are disclosed, for example, in "Handbook of Epoxy Resins" by Lee and Neville, referred to above.

The epoxy resin is cured in the conventional manner using conventional epoxy curing agents. The curing of the epoxy resin is conventional, and suitable curing agents are disclosed in abundance, for example, in the aforesaid "Handbook of Epoxy Resins." The preferred curing agents are aromatic diamines and the like, but satisfactory results can be obtained with other curing agents such as the anhydrides and Lewis acids, particularly boron trifluoride monoethylamine complex. When anhydrides are used, it is preferable to employ a conventional accelerator such as DMP 30 or BDMA or other tertiary amines.

Excellent results are obtained by using curing agent Z, which is an eutectic mixture of metaphenylene diamine and methylenedianiline. Other excellent curing agents include MPDA (metaphenylene diamine), MA (maleic anhydride) and DDSA (dodecyl succinnic anhydride). The amount of curing agent used is conventional and usually slightly less than the stoichiometric amount (for example, between 85 and 95 percent of the theoretical).

When using an epoxy resin such as Epon 828 or other diglycidyl ether of a bisphenol A, the preferred curing agent is curing agent Z or other aromatic diamine, and the amount by weight of the curing agent is usually about 15 to 25 percent of the weight of the epoxy resin. For example, preferably about 18 to 22 parts by weight of curing agent Z are used with 100 parts by weight of Epon 828.

If the curing agent is an anhydride, the amount of the curing agent may equal or exceed the amount of Epon 828 or other epoxy resin. For example, 98 parts by weigh of chlorendic anhydride could be used with 100 parts of Epon 828. It would be preferable to include also an accelerator such as DMP 30 or tris (dimethylaminomethyl) phenol, in an amount equal to about 1 percent of the weight of the anhydride.

Epon 828 is a liquid epichlorohydrin bisphenol A condensation product having an epoxide equivalent of 185 to 192 and a molecular weight of 350 to 400. It is a standard liquid aliphatic epoxy resin and has a viscosity of 100 to 160 poises at 25°C.

The thermosetting resin binder used in the grinding wheels of this invention may also be a conventional polyurethane binder of the type suitable for grinding wheels, such as a polyester or polyether polyurethane formed by reacting a polyhydric alcohol or a linear hydroxy-terminated polyester or polyether having at least 2 terminal hydroxyl groups and a molecular weight of at least 250 with an organic polyisocyanate having 2 to 3 functional isocyanate groups.

A suitable polyurethane composition can, for example, be made by mixing about 0.09 to 1.5 equivalent weights of an organic polyisocyanate, such as 2,4- or 2,6-toluene diisocyanate or 4,4'-diphenylmethane diisocyanate or other diphenyl alkane diisocyanate or the like, with one equivalent weight of a polyol having a molecular weight of 250 to 4000 (preferably 400 to 2000), such as a dihydroxy-terminated polyester, a poly (alkylene ether) glycol or the like. This may be cured by using excess diisocyanate, a suitable diol, triol, diamine or triamine, or a curing agent, such as dicumyl peroxide, di-tertiary butyl peroxide or other curing agents as disclosed, for example, in U.S. Pat. Nos. 2,953,539 and 3,028,353.

While many different polyisocyanates may be used to form the polyurethane, it is desirable to employ an aromatic diisocyanate having at least 6 carbon atoms, such as toluene diisocyanate (TDI) or a 4,4'-diphenylmethane diisocyanate (MDI) or modifications of these, such as an 80:20 or 65:35 blend of 2,4- and 2,6-toluene diisocyanate.

The polyurethane may be made from various polyester and polyether polyols having a molecular weight greater than 250 such as polyalkylene adipates and other hydroxy-terminated polyesters or poly (alkylene ether) glycols, such as polyethylene glycol, polypropylene glycol or the like. Excellent results are obtained using conventional polyurethane prepolymers.

The polyurethanes are generally prepared by reacting a polyol (a polyhydric alcohol or a hydroxy-terminated polyester or polyether) with a polyisocyanate under anhydrous conditions to form a liquid polymer having essentially either all hydroxyl end groups or all isocyanato end groups and then curing by adding equivalent amounts of polyisocyanate or polyol, respectively, as is well understood in the art. These and other polyurethanes may be used in the grinding wheel of this invention including those disclosed in U.S. Pat. No. 3,142,081.

The polyether polyol used to form the polyurethane may be based on propylene oxide and may, for example, be a conventional propylene oxide adduct of glycerol having an average molecular weight of about 1000 to 3000 and having 3 primary hydroxyl radicals.

The resin binder used in the grinding wheel of this invention may also be a conventional phenol-aldehyde

resin such as Bakelite 5417 or other phenol-formaldehyde resin or other commercial phenolic resin commonly used in grinding wheels. Such phenolic resin may incorporate suitable wetting agents, such as creosote oil, xylol, kerosene or the like. The resin composition preferably includes a filler, such as cryolite, asbestos, or other standard filler.

The abrasive material used in the grinding wheels of this invention may be of various types including silicon carbide, aluminum oxide, zirconium alloys, corrundum, emery, and garnet. Any of the abrasives commonly used in surface grinders may be used in wheels made by this invention with particle sizes from 30 mesh to 100 mesh or finer. However, the type of abrasive used and the grit size depends on the particular application, and it is often desirable to employ extremly hard materials such as silicon carbide. For many applications aluminum oxide or a mixture of aluminum oxide and silicon carbide is preferred. Generally it is desirable to use a friable aluminum oxide so that glazing is reduced. It is usually preferable to employ aluminum oxide with a friability of 30 to 80 on the friability index, more preferably in the range of 50 to 60, and a particle size from about 30 grit to about 100 grit, more preferably 54 grit or smaller.

In the double-disc grinding machines used to grind disc brake rotors, the abrasive used in grinding wheels is preferably a mixture of 50 to 90 percent by weight of silicon carbide (more preferably 75 to 90 percent), and 10 to 50 percent by weight of aluminum oxide (more preferably 10 to 25 percent).

The grinding wheel compositions of this invention can sometimes omit fillers, but it is usually preferable to incorporate a conventional filler such as mica, titanium dioxide, talc, graphite, or clays. It is preferable to avoid those fillers which absorb water or to carry out the processing so that the composition is essentially free of water. When using an epoxy resin or a polyurethane as the binder, the preferred filler is mica.

The refractory compositions of the present inventions may include an amount of finely divided mica or other inorganic filler in an amount of up to 30 percent of the total weight of the thermosetting resin binder (i.e., the total weight of the resin and curing agent, if any). The amount of such filler is preferably about 10 to 25 percent of said total weight.

In carrying out the present invention, it is preferable to employ polystyrene or "Styropor" beads of the type commonly used to make foam plastic cups and the like. Such polystyrene beads may be initially formed with a relatively small size and may contain an expanding agent such as petroleum ether or other volatile hydrocarbon. Such expandable gas-filled polystyrene beads are usually preexpanded in a suitable apparatus such as a Rodman steam preexpander as disclosed, for example, in the book "Polystyrene" by W. C. Teach and G. C. Kiessling, Copyright 1960 by Reinhold Publishing Corporation. The particles are thus expanded using steam or a source of heat. The expanded beads are available commercially with a density in a range of 1 to 4 pounds per cubic foot with various diameters.

In this invention it is preferable to employ preexpanded polystyrene beads with a diameter from about 0.03 to about 0.2 inch, depending on the particle size of the abrasive grains, and a density from about 1.5 to 5 pounds per cubic foot. (more preferably 2 to 4 pounds per cubic ft.). The preexpanded beads are usually generally spherical or round, and they are available in fairly uniform sizes. However, satisfactory results can be obtained using preexpanded polystyrene of suitable size which is in the form of chunks or irregular shapes with a density, for example, no greater than 5 pounds per cubic foot. It is also possible to obtain some of the advantages of the invention with beads having a density of 5 to 10 pounds per cubic foot.

The size of the polystyrene beads or other beads can be very important for a particular application of the grinding wheel. In some instances, the size of the beads must be maintained in a range from about 0.03 inch to about 0.13 inch (for example, when using abrasive grains from 60 to 100 mesh or finer). In other cases the size can be up to 0.2 or 0.3 inch, and for many applications it is desirable to mix the smaller beads with extremely large beads or chunks to form large voids in the grinding surface. For most applications the majority of the beads should have a diameter or particle size of at least 0.05 inch, such as 0.05 to 0.15 inch or 0.08 to 0.2 inch. The bead size should be substantially greater than the grit size of the abrasive and is preferably at least several times said grit size.

In some applications as, for example, in disc or face grinders with a wide radial face of 3 to 20 inches or more, the loading or glazing problem can be a serious one and, therefore, it becomes desirable to mix the regular-size polystyrene beads with relatively large beads having a diameter of 0.2 to 0.3 inch or larger and a relatively low density, such as 1 to 2 pounds per cubic foot. If, for example, the refractory composition used to form the grinding wheel of this invention contains 10 to 35 percent by volume of polystyrene or other thermoplastic resin beads with a density of 1.5 to 5 pounds per cubic foot, then such composition may contain 7 to 25 percent by volume of beads with a particle size from 0.03 to 0.15 inch and about 20 to about 5 percent by volume of larger beads with a size from about 0.2 or 0.3 to about 0.6 inch.

When using an epoxy resin binder, it is usually preferable to premix the epoxy resin and the curing agent and then add the refractory particles and mica or other reinforcing agent before the preexpanded beads are added. Such beads can be uniformly distributed in the epoxy resin composition by simply mixing it about room temperature. The resulting mixture is relatively dry and does not flow too readily but can be forced into a suitable mold to form the desired shape. In the casting process, the beads do not separate out and rise to the surface as one might expect. We believe that there is some surface action or affinity between the beads and abrasive grains brought about by the epoxy resin. Mica as a filler helps and causes increased viscosity and somewhat different surface action.

After the casting, the molded article may be cured in an oven for a suitable time to effect proper curing of the epoxy resin. The temperature is preferably maintained in the range of 300° to 350°F. for a suitable period of time, which is usually at least 3 hours and may be 6 to 8 hours or more. At these temperatures the preexpanded thermoplastic beads resist melting and therefore form the desired voids. Therefore, it is possible to produce a soft or medium grinding wheel suitable for flat surface grinding.

The polystyrene beads used in the grinding wheel of this invention are available commercially with varying melting points and densities (for example, Styropor resins made by Wyandotte Corp.). It is preferable to employ polystyrene with a melting point in the range of

about 350° to 600°F. or one which will resist melting at the temperatures used for curing of the epoxy resin or other binder. The thermoplastic beads must melt at a temperature below 800°F. and must resist melting during the cure sufficiently to function in the desired manner. To function best, they should have a melting point no greater than 600°F. The upper limit will depend on the type of binder and somewhat on the efficiency of the cooling and on the temperatures actually reached in the grinding operation. The melting point is preferably about 400° to 600°F. for beads used in a wheel employing a phenol-formaldehyde binder and is preferably about 350° to 500°F. for beads used in a wheel employing a polyurethane binder or an epoxy binder.

While it is preferred to use gas-filled polystyrene beads in the wheel of this invention or pieces formed of homopolymers or copolymers of styrene, it will be understood that various other thermoplastic synthetic resin materials may be used which have melting points in the desired range and comparable physical characteristics and which are suitable for use with the epoxy resin. Thus, a substantial number of thermoplastic resins could be used having melting points in a range of about 350° to about 600°F. including nylon, polyesters, vinyl resins, acrylate resins and various other thermoplastic resins. It would be unsatisfactory to employ beads formed of thermosetting resins or glass because they could not melt, shrivel or deform under heat and could not function as required in the wheel of this invention.

Using American Standard markings for grinding wheels, a typical wheel made according to the invention might be identified as CA54F10B, where F indicates the grade or hardness and 10 indicates the structure. The grades of grinding wheels range from A to Z and the structure numbers go from 0 to 20 or more. The synthetic resin compositions of the present invention are useful for surface grinding wheels with silicon carbide or aluminum oxide refractory of 36 to 80 grit, a grade of AA to M (preferably B to J) and a structure of 0 to 20 (preferably 8 to 16).

The abrasive grains used in grinding wheels usually have refractory grains, such as silicon carbide or aluminum oxide, in standard sizes, such as 30, 36, 46, 54, 60, 70, 80, 90 or 100 grit.

The common abrasives, such as silicon carbide and aluminum oxide, are usually used in the practice of this invention, but harder abrasives such as diamonds could also be used. In surface grinding operations, where aluminum oxide is desired, it is usually preferable to use a friable aluminum oxide to avoid glazing and to obtain a better cutting action and cooler operation. In the practice of this invention, best results are usually obtained with aluminum oxide particles having a friability of 35 to 60 on the friability index.

The optimum recipe for a grinding wheel will depend on the type of binder employed as well as on the type of grinding operation involved. The preferred ranges for epoxy resin compositions are, of course, somewhat different than those for polyurethane compositions or phenolic compositions. This will be apparent from the description below.

When using an epoxy resin binder, such as a diglycidyl ether of a bisphenol A, the refractory composition used to make the grinding wheel according to this invention may comprise from about 40 to 75 percent by volume (preferably a major amount by volume) of refractory grains and from about 10 to 35 and preferably about 10 to about 25 percent by volume of the thermoplastic beads. In such refractory composition the amount by weight of said refractory grains is preferably from about 5 to about 7 times the total weight of the epoxy resin (including the curing agent) and the amount of mica or other filler is up to 30 percent and preferably about 10 to 25 percent of said total weight. The refractory epoxy composition may be as disclosed in our application Ser. No. 359,109 filed May 10, 1973, which is incorporated herein by reference. The epoxy resin used in refractory composition is preferably one which permits molding of the grinding wheels and curing for 3 to 8 hours at a temperature from about 300° to about 350°F., and the thermoplastic beads preferably melt at a temperature from about 350° to about 500°F.

When using a polyurethane binder, the refractory composition used to make the grinding wheel according to this invention may comprise from about 40 to 75 percent by volume of refractory grains and from about 5 to about 35 percent and preferably 7 to 20 percent by volume of the thermoplastic beads (more preferably 10 to 15 percent by volume). In such refractory composition the amount by weight of said refractory grains is from about 3 to about 6.5 times the total weight of the polyurethane (including any curing agent) and is preferably from about 4 to about 6 times said total weight, and the amount of mica or other filler is up to 25 percent and preferably 5 to 20 percent of said total weight. The polyurethane used in the refractory composition is preferably one which permits molding of the grinding wheel and curing for 3 to 8 hours at a temperature from about 300° to 350°F., and the thermoplastic beads preferably melt at a temperature from about 350° to about 500°F.

It is usually preferred to employ the prepolymer method when forming polyurethane-bonded grinding wheels according to this invention. The prepolymer may, for example, be prepared in the conventional manner from MDI or TDI and a hydroxy-terminated polyether or polyester with a molecular weight of 250 to 3000, such as a poly (propylene glycol) or other conventional polyol. The polyol should contain less than 0.005 percent by weight of water. The prepolymer should preferably have a NCO/OH ratio of 2.0 to 2.05 and should be preferably 100 percent solids. The prepolymer is preferably stored at a temperature below 50°F. for no more than a few days before being used.

The procedures for making the high-density polyurethanes and the materials used, including the diisocyanates and the hydroxy-terminated polyesters or polyethers, are conventional and are disclosed for example in the books "The Development and Use of Polyurethane Products" by E. N. Doyle, Copyright 1971 by McGraw-Hill Book Company and "Polyurethane Technology" by Paul F. Bruins, Copyright 1969 by John Wiley & Sons, Inc.

When using a conventional commercial urea-formaldehyde or phenol-aldehyde binder, the refractory composition used to make the grinding wheel according to this invention may comprise from about 40 to 75 percent by volume of refractory grains and from about 10 to about 35 percent and preferably 10 to 25 percent by volume of the thermosetting beads having a melting point from about 350° to about 600°F. In such refractory composition the amount by weight of said refractory grains is from about 5 to about 9 times and preferably 6 to 8 times the total weight of the phenolic

binder, and the amount of cryolite or other filler is up to 25 percent and preferably 5 to 20 percent of said total weight. For example, the composition may contain 0.5 to 20 parts of cryolite and 0.5 to 3 parts of quicklime per 100 parts by weight of the phenol-formaldehyde binder.

Such binder is one which permits curing of said refractory composition at a temperature below 500°F, and preferably not in excess of 400° to 450°F., and the curing or setting time is preferably no more than 50 hours with a maximum curing temperature of 350° to 450°F. The polystyrene beads or other thermoplastic beads used in said composition have a melting point above 350°F. and above the aforesaid maximum curing temperature (preferably a melting point in the range from about 400° to about 600°F.).

The phenol-aldehyde resin binders suitable for use in the composition of this invention may be various conventional phenolic resins and may be formed in various ways, for example, by reacting a molar excess of the aldehyde with phenol to form a liquid "A-stage" resin and thereafter molding the product and curing it to form an infusible insoluble "C-stage resin." The aldehyde is preferably formaldehyde, but excellent results can be obtained when incorporating minor amounts of furfural or other aldehydes.

Various phenolic molding powders are available commercially which may be used in the practice of this invention. They may be made in various ways, for example, by reacting 1.5 to 2.5 moles of formaldehyde with 1 mole of phenol in the presence of an acid or an alkaline catalyst.

The phenol-formaldehyde molding powders and other phenolic resins suitable for use as binders in the compositions of this invention generally require at least 5 and preferably 10 to 50 hours for curing or setting up the resin to the desired infusible, insoluble, solid state. For example, after the refractory composition of this invention containing the phenolic resin binder has been completely mixed, it may be pressed at room temperature using a pressure of 500 to 3000 pounds per square inch and, thereafter, the pressed green grinding wheel may be placed in an electrically-controlled oven and cured using a baking cycle which starts at 150°F. or so and ends at about 350° to 450°F. (preferably 350° to 400°F.). The temperature may be stepped up gradually or in increments of 20° to 50° so that the overall curing cycle takes anywhere from 15 to 100 hours. This is conventional practice and the method of curing forms no part of this invention.

When using commercial phenolic molding powders as described above, it is known that the results can be improved by proper use of wetting agents, fillers and other conventional additives and that furfural can be employed as well as other compounds such as furfuryl alcohol and the like. For example, 0.5 to 5 parts of a wetting agent or neutral oil such as xylol, kerosene or creosote oil can be added per 100 parts by weight of the phenol-formaldehyde molding powder. Also 5 to 15 parts of furfuryl alcohol or furfural can be used per 100 parts by weight of the molding powder. It is also desirable to employ 1 to 20 parts by weight of cryolite plus 0.5 to 3 parts of quicklime per 100 parts by weight of the powder.

The wetting agents are desirable to cause the molding powder to stick to the refractory grains and to stick to the thermoplastic polystyrene beads. If desired the abrasive grains and/or the thermoplastic beads may be wetted with a liquid phenolic resin of low viscosity or furfural. Also the wetted grains may be tumbled with a mixture of the molding powder and the filler to cause a more uniform deposit of the powder on the refractory grains. Such mixing procedures are well known in the art, and it will be understood that these and other known mixing procedures may be used in the practice of the present invention.

While advantages of the invention can be obtained using urea-formaldehyde binders and other binders which are less suitable in the grinding wheel art, best results are obtained using the binders more suitable for grinding wheels, particularly epoxy resin binders, polyurethane binders and phenol-formaldehyde binders. Suitable binders are disclosed in the examples which follow, it being understood that these are intended to illustrate possible ways that the polystyrene beads may be used with various conventional binder systems.

EXAMPLE I

An epoxy resin composition is prepared according to the following recipe:

	Parts by weight
Silicon carbide (54 mesh)	76
Aluminum oxide (54 mesh)	8.3
Epon 828	11.7
Curing agent z	2.4
Mica (water ground, 325-mesh)	1.6

The Epon 828 and curing agent z are premixed and then mixed with the silicon carbide and aluminum oxide particles for at least 5 minutes. The mica is added toward the end of the mixing.

To this mixture is added preexpanded polystyrene beads with a diameter of approximately one-eighth inch (much greater than that of the abrasive grains) and a density of 4 pounds per cubic foot in an amount such that there is formed a mixture containing about 18 to 20 percent by volume of said beads. After this mixture is thoroughly mixed to provide uniform distribution, it is deposited in a suitable wheel mold and cured for 4 to 6 hours at a temperature of 300°F. to produce a grinding wheel with a specific gravity of about 1.8.

EXAMPLE II

An epoxy resin composition is prepared according to the procedure of the previous example using the following recipe:

	Parts by weight
Aluminum oxide (54 mesh)	84.3
Epon 828	11.7
Curing agent z	2.4
Mica (water ground, 325-mesh)	1.6

To the resulting composition, there is added a mixture of (a) regular polystyrene beads as in the previous example having a diameter of one-eighth inch and a density of 4 pounds per cubic foot and (b) large polystyrene beads having a diameter of one-half inch and a density of 2 pounds per cubic foot. The amounts of the polystyrene beads used are such that there is formed a mixture containing about 14 percent by volume of the ⅛-inch polystyrene beads and about 6 percent by volume of the ½-inch beads. This mixture is then mixed, placed in a mold, and cured substantially as in the previous example.

The resulting grinding wheel has generally the same advantages as that of Example I with respect to grinding but is not quite as strong. The large beads are advantageous in disc or face grinders where the radial face width is substantial, such as 3 to 20 inches or more, and they enable it to function properly without loading or glazing.

EXAMPLE III

A grinding wheel generally similar to that of Example I can be made of a refractory composition similar to that of Example I and containing the same refractory material, the same filler and the same polystyrene beads but employing a conventional thermosetting polyurethane resin binder instead of the Epon 828 and Curing agent *z*. Such composition could, for example, employ 10 to 15 percent by volume of polystyrene beads and an amount by weight of the refractory grains equal to about 5 to 6 times the total weight of the polyurethane binder and could employ as the binder a conventional polyether urethane formed by reacting an aromatic diisocyanate, such as MDI, with a hydroxy-terminated polyether (polyol) having a molecular weight of 500 to 1500, such as a poly (propylene glycol) or other polyol containing less than 0.005 percent by weight of water.

One suitable procedure is to react the MDI with such polyether polyol to form a 100 percent solid prepolymer with an NCO/OH ratio of 2.05; thereafter to mix the prepolymer with a small amount of benzoyl chloride, such as 1 percent, and an amount of a polyether polyol (such as said polypropylene glycol) or a curing agent sufficient to effect the desired curing or hardening of the composition, and then to add the refractory grains, the mica and the polystyrene beads. After the materials are thoroughly mixed and preferably less than 10 minutes after the mixing is initiated, the composition is loaded into the mold and cured for a suitable period of time, such as 3 to 8 hours at a temperature of 300° to 350°F. to produce the desired grinding wheel (or wheel segment).

Various conventional procedures may be employed to form the polyurethane-bonded grinding wheel provided that the polystyrene beads are incorporated in the mix before the molding and curing and that curing is effected without premature melting of the beads.

In this Example the polyether polyol used to form the prepolymer and to cure the polyurethane to the solid insoluble infusible state may be a trimethylol propane or a polypropylene glycol or a commercial polyoxypropylene glycol derivative having an equivalent weight of 200 to 1000 or a commercial polyether diol or triol such as Triol TP440, Pluracol 463 or Pluracol P1010 made by Wyandotte Chemicals Corp. In the practice of the invention, various polyether polyols may be employed having a molecular weight from 250 to 4000, and it is preferred to use those with an equivalent weight of about 100 to 1000.

EXAMPLE IV

A grinding wheel generally similar to that of Examples I and III can be made of a refractory composition similar to that of Example I and containing the same refractory material, and the same polystyrene beads in essentially the same amounts but employing a conventional phenol-formaldehyde resin binder instead of the Epon 828 and Curing agent Z. Such composition could, for example, employ the same amount of the polystyrene beads and an amount by weight of the refractory grains equal to 6 to 8 times the total weight of the phenolic binder and could employ as the binder a conventional phenol-formaldehyde of the type commonly used in grinding wheels.

A binder mixture could, for example, be prepared substantially according to the following recipe:

	Parts by weight
Phenol-Formaldehyde molding powder (Bakelite 5417,200-mesh)	100
Creosote Oil (Carbosota)	1–5
Furfural	5–15
Cryolite	10–15
Quicklime	1.5–3

A suitable procedure would be to mix the phenolic molding powder with the creosote oil and half of the furfural, then to add the remaining half of the furfural, thereafter to add the cryolite and lime, and then to add the polystyrene beads. Any conventional mixing procedure can be used if the beads are added last.

The composition should be thoroughly agitated as in a conventional mixer to obtain proper adhesion to the refractory grains. After thorough mixing, the resulting mixture may be placed into a mold and pressed at a high pressure such as 1000 to 3000 pounds per square inch to provide a grinding wheel or segment with a suitable density, such as a specific gravity of about 2.1. The molded product may then be cured in various ways at temperatures up to 350° or 400°F. for a suitable period of time, such as 15 to 30 hours, to provide the desired degree of cure. For example, a suitable cure might be effected by initially heating for 8 to 10 hours at 200°F., thereafter heating for an additional 2 hours at 240°F., and for an additional 2 hours at 320°F., and then holding the temperture at 350° to 360°F. for several hours or until the desired curing is completed.

It will be understood that polyurethane binders or phenolic binders of the type set forth in Examples III and IV may also be used to replace the epoxy resin binder of Example II.

In the above examples it is preferable to employ aluminum oxide with a friability in the range of 35 to 60 (for example, a ball-milled aluminum oxide which is about 55 on the friability scale.)

A formulation of the type in Example I, for example, could be employed to produce a large diameter straight-cup inserted-nut surface grinding wheel (or disc wheel) with a thickness of 1 inch to 1.5 inches, an axial length at the periphery of about 4 inches, and a flat annular grinding face with an internal diameter of 27 to 29 inches and an external diameter of 32 inches. Such a wheel would be suitable for surface grinding at speeds of 4000 to 9000 surface feet per minute.

Pairs of straight-cup epoxy-bonded grinding wheels with an external diameter of about 32 inches made according to this invention have been used in conventional double-disc grinders used to grind flat brake rotors for automobile disc brakes and have been found to be far superior to the phenolic grinding wheels which were previously considered best suited for this grinding operation. The typical procedure for grinding such brake rotors (or discs) is to rotate the brake rotor at a substantial speed (perhaps more than 100 revolutions per minute) while rotating the two grinding wheels in opposite directions to effect simultaneous grinding of both faces of the brake rotor in a short period of time, such as 12 to 20 seconds. The amount of grinding on

each face may be, for example, about 0.005 inch so that the thickness of the rotor is reduced by 0.01 inch to the desired thickness.

An epoxy grinding wheel made according to the present invention and containing polystyrene beads has a useful life at least three to four times that of the previously used phenolic grinding wheels in such a double-disc grinding operation, and such epoxy wheel operates at a lower temperature with a more effective cutting action and produces a higher percentage of premium parts because of more uniform grinding. The prior art resinoid wheels that were previously used in such double-disc grinding machines produced disc brake rotors with more variations in thickness and substantially fewer premium parts.

The refractory compositions of the type given in the above examples are suitable for making flat disc grinding wheels as well as cup-shaped wheels or segmented wheels such as the Type No. 6 straight-cup wheel disclosed on page 33 of the book "Grinding Wheels and their Uses" by Johnson Heywood, Copyright 1942 by the Penton Publishing Co. or the segmental wheel disclosed in FIG. 9 on page 34 of that book. Such wheels effect grinding over a flat annular face or annular zone with a radial width from 1 to 6 inches and a diameter from 6 inches to several feet. The wheel speeds used depend on the grinding operation being performed and can, for example, be in the range of 4000 to 10,000 surface feet per minute or higher.

The thermosetting binders used in the practice of this invention are preferbly selected to provide a rigid or substantially rigid product and to minimize foaming. The binder composition is preferably of the non-foaming type and one which produces a rigid structure rather than a flexible one.

As used in the specification and claims, the term "high-density" as applied to a polyurethane indicates that foaming has been minimized and that the composition has not been compounded in an attempt to obtain a material expansion and reduction in density.

The term "gas-filled" is used herein to distinguish from beads containing an oil or liquid rather than air. Such terms does not require an imperforate or closed-cell structure.

It will be understood that variations and modifications of the specific methods, compositions and articles disclosed herein may be made without departing from the spirit of the invention.

Having described our invention, we claim:

1. A process of the character described comprising reacting epichlorohydrin with bisphenol A to provide a liquid condensation product with an epoxide equivalent of at least 180 and a molecular weight of about 350 to about 400, mixing said condensation product with an aromatic diamine curing agent to form an epoxy resin binder, mixing one part of said epoxy resin binder with about 5 to about 7 parts by weight of aluminum oxide having a particle size from about 36 grit to about 80 grit, with about 10 to 30 parts by weight of mica and with gas-filled polystyrene beads with a diameter from 0.05 to 0.2 inch and a density from about 1.5 to 10 pounds per cubic foot to form a composition containing at least 50 percent by volume of said aluminum oxide and from about 10 to 30 percent by volume of said polystyrene, and heating said composition to a temperature not in excess of 350°F. for at least several hours to harden and set the same.

2. A process according to claim **1** wherein said composition is cured for 3 to 8 hours at a temperature of from about 300° to about 350°F. to form a surface grinding wheel.

3. A process comprising forming a surface grinding wheel from a refractory composition comprising a major amount of volume of abrasive refractory grains having a particle size of from about 36 mesh to about 80 mesh, from about 10 to about 30 percent by volume of gas-filled organic thermoplastic synthetic resin beads with a diameter from 0.05 to 0.15 inch, and a thermosetting synthetic resin binder which can be cured at a temperature of 450°F. or below, the amount by weight of said refractory grains being from about 4 to about 8 times the total weight of said resin binder, and heating said composition to harden and cure the same without melting all of said beads so that the beads from voids in the cured wheel, said beads being formed of a thermoplastic material with a melting point not in excess of 500°F.

4. A process according to claim **3** wherein said binder is glycidyl ether of a polyhydroxy phenol and has at least two glycidyl ether groups, said thermoplastic beads having a melting point from about 350° to about 500°F., and said refractory composition is cured for at least several hours at a temperature from about 300° to about 350°F., and wherein the amount by weight of said refractory grains is from about 5 to about 7 times the total weight of said epoxy binder.

5. A process according to claim **3** wherein said binder is a phenolaldehyde resin, said thermoplastic beads have a melting point from about 350° to about 600°F., and said refractory composition is cured from 10 to 50 hours at a temperature from 150° to 450° including at least 2 hours at a temperature from 350° to 450°F. and wherein the amount of weight of said refractory grains is from about 5 to about 9 times the total weight of said binder.

6. A process according to claim **3** wherein said binder is a polyurethane reaction product of a polyhydric alcohol having a molecular weight of at least 500 and a polyisocyanate having 2 to 3 isocyanato groups, said thermoplastic beads have a melting point from about 350° to about 600°F., and said refractory composition is cured for at least several hours at a temperature from about 300° to about 350°F., and wherein the amount by weight of said refractory grains is from about 3 to about 6 times the total weight of said polyurethane binder.

7. A process according to claim **3** wherein said grinding wheel has a generally flat grinding face and is rotated about an axis perpendicular to said face at a speed of 4000 to 10,000 surface feet per minute, and wherein said grinding face is moved into engagement with a flat metal surface and an effective cutting action is maintained by causing the exposed beads at the outer surface of said grinding face to melt and break away, thereby minimizing loading and glazing of the wheel.

8. A refractory epoxy composition for making surface grinding wheels comprising from about 45 to about 75 percent by volume of abrasive refractory grains with a particle size from about 36 to about 80 grit, from about 10 to about 25 percent by volume of organic thermoplastic vinyl resin beads with a particle size substantially greater than that of the refractory grains and no more than 0.2 inch, a diglycidyl ether resin binder which may be cured at a temperature not in excess of 350°F. without melting said beads, the amount by weight of said refractory grains being from

about 5 to about 7 times the total weight of said binder, and 10 to 30 parts of a filler per 100 parts by weight of said binder.

9. A rigid molded resin-bonded grinding wheel designed for flat surface grinding and formed by curing a refractory composition comprising a major amount by volume of finely divided abrasive refractory grains having a particle size of from about 36 to about 80 mesh, from about 10 to about 30 percent by volume of gas-filled organic thermoplastic synthetic resin beds having a particle size of from about 0.05 to about 0.2 inch and a density no greater than 5 pounds per cubic foot, at least 10 percent by weight of finely divided inorganic filler, and a thermosetting synthetic resin binder which can be cured at a temperature not in excess of 450°F. to provide a strong rigid structure, and beads having a melting point below 600°F. and sufficient resistance to melting during curing of the wheel to form large voids in the cured wheel, the amount by weight of said refractory grains being from about 4 to about 8 times the total weight of said binder.

10. A surface grinding wheel according to claim **9** wherein said binder is selected from the group consisting of phenol-aldehyde resins, polyurethanes, and epoxy resins.

11. A surface grinding wheel according to claim **9** wherein said beads have a particle size of at least one-eighth inch.

12. A surface grinding wheel according to claim **9** wherein said beads comprise expanded polystyrene with a density of about 2 to about 4 pounds per cubic foot.

13. A surface grinding wheel according to claim **9** wherein said beads have a melting point not in excess of 500°F.

14. A surface grinding wheel according to claim **9** wherein said binder is an epoxy resin, said beads have a melting point not in excess of about 500°F., and wherein the amount by weight of said refractory grains is from about 5 to about 7 times the total weight of said binder.

15. A surface grinding wheel according to claim **9** wherein said binder is a glycidyl ether of a bisphenol A and said beads having a melting point of from about 350° to about 500°F., a particle size from about 0.05 to about 0.2 inch, and a density from about 1.5 to about 4 pounds per cubic foot.

16. A rigid molded epoxy-bonded grinding wheel designed for flat surface grinding and formed by curing a refractory composition comprising a major amount by volume of abrasive refractory grains having a particle size of from about 36 to about 80 mesh, from about 10 to about 30 percent by volume of expanded gas-filled organic thermoplastic synthetic resin particles having a particle size of from about 0.05 to about 0.15 and a density no greater than 4 pounds per cubic foot, at least 10 percent by weight of finely divided inorganic filler, and an epoxy resin binder which can be cured at a temperature not in excess of 450°F., said thermoplastic resin having a melting point not in excess of about 500°F., the amount of weight of said refractory grains being from about 5 to about 7 times the total weight of said binder.

17. A surface grinding wheel having a flat grinding face located substantially in a plane perpendicular to the axis of rotation with a radial width of 1 to 6 inches and a diameter of at least 1 foot, said grinding face being formed a from a curable refractory composition comprising a major amount by volume of abrasive refractory grains having a particle size of from about 30 to about 80 grit and being selected from the group consisting of aluminum oxide and silicon carbide, from about 10 to about 30 percent by volume of gas-filled organic thermoplastic synthetic resin beads having a melting point not in excess of 500°F. and a particle size from about 0.05 to about 0.2 inch, at least 10 percent by weight of a finely divided inorganic filler, and a thermosetting synthetic resin binder which can be cured at a temperature below the melting point of the beads, the amount by weight of said refractory grains being from about 4 to about 8 times the total weight of said binder, the amount of said filler being up to 30 percent by weight.

18. A surface grinding wheel according to claim **17** wherein said thermosetting binder is a rigid high-density polyurethane formed by reacting a polyisocyanate having 2 to 3 isocyanato groups with a polyol having 2 to 4 terminal hydroxyl groups and an equivalent weight of from about 100 to about 1000.

19. A surface grinding wheel according to claim **17** wherein said thermosetting binder is formed by reacting a molar excess of formaldehyde with phenol and wherein said beads are formed of a vinyl resin.

20. A surface grinding wheel according to claim **17** wherein said refractory composition contains at least 14 percent by volume of thermoplastic beads with a particle size of at least one-eighth inch.

21. A high-strength surface grinding wheel according to claim **17** having a specific gravity from about 1.8 to about 2.1, a grade of B to J and a structure of 8 to 16.

22. A surface grinding wheel according to claim 21 wherein the refractory grains are aluminum oxide and the resin binder is a diglycidyl ether of a bisphenol.

23. A surface grinding wheel with a flat grinding face having a radial width of at least 3 inches, said grinding face being formed by curing a refractory composition comprising at least 40 percent by volume of abrasive refractory grains selected from the group consisting of aluminum oxide, silicon carbide and mixtures thereof, from about 10 to about 35 percent by volume of gas-filled organic thermoplastic synthetic resin beads with a density from about 1.5 to about 5 pounds per cubic foot including from about 7 to about 25 percent by volume of beads having a particle size from about 0.03 to about 0.15 inch and from about 20 to about 5 percent by volume of larger beads having a size from about 0.2 to about 0.6 inch, and a thermosetting epoxy resin binder which can be cured at a temperature below the melting point of the beads, the amount by weight of said refractory grains being from about 4 to about 8 times the total weight of said binder, said beads having a melting point not in excess of 500°F.

24. A surface grinding wheel according to claim **23** wherein said grinding face has a radial width from about 5 to about 20 inches and said larger beads have a diameter from about 0.3 to about 0.6 inch and a density not in excess of 4 pounds per cubic foot.

25. A rigid molded epoxy-bonded grinding wheel designed for flat surface grinding and formed by curing a refractory composition comprising at least 50 percent by volume of abrasive refractory grains having a particle size of from about 30 to about 100 mesh, from about 5 to about 20 percent by volume of organic thermoplastic synthetic resin beads having a particle size of from about 0.2 to about 0.3 inch and a density no

greater than 4 pounds per cubic foot, at least 10 percent by weight of finely divided inorganic filler, and a diglycidyl ether resin binder which can be cured at a temperature not in excess of 350°F., said thermoplastic resin beads having a melting point of from about 350° to about 500°F., the amount by weight of said refractory grains being from about 5 to about 7 times the total weight of said binder.

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