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(54) **Means and methods for abrading a work surface.**

(57) The invention relates to honing, polishing, reducing, or otherwise abrading, in which improved means and methods are employed for abrasion of workpieces (10) in general, and at least selected internal portions (16) of workpieces (10) such as bores, passages, and cavities in particular. In general, the abrasion is accomplished by the use of a flowable abrasive medium (18), with particular embodiments using a visco-elastic, rheopectic abrasive medium.

The abrasive medium (18) is in the form of a plastic or semisolid matrix containing abrasive particales (120) distributed substantially uniformly throughout the matrix. The matrix transports the particles (120) through or across selected portions of a workpiece (122) being reated in order to permit the abrasive particles (120) to remove upraised metal and to round or radius corners as it passes, or to otherwise uniformly remove or finish these portions. Uniform distribution and maximised abrasive effect of the particles (120) is obtained by use of the matrix which also provides a relatively firm backing for the abrasive when the medium is subjected to high pressure.

Title: Means and Method for Abrading A Work Surface

This invention relates to honing, polishing, reducing, or otherwise abrading, in which improved means and methods are employed for abrasion of workpieces in general, and at least
5 selected internal portions of workpieces such as bores, passages, and cavities in particular. In general, the abrasion is accomplished by the use of an abrasive medium, and more particularly by the use of a visco-elastic, abrasive medium.

In one embodiment, this abrasive medium comprises a visco-
10 elastic, rheopectic matrix, having the consistency of putty (at room temperature and with no pressure applied) which is permeated with finely divided and evenly dispersed abrasive particles. When passed across and against a work surface in the proper manner, this abrasive medium provides maximum abrasive action and uniformity of finish. In the context of this invention, "rheopectic"
15 defines the property of a composition in which the viscosity increases with time under shear or a suddenly applied stress. Stated another way, this property of the abrasive medium is exactly opposite of "thixotropy".

20 The invention also deals with the discovery that visco-elastic materials adhere strongly to porous or roughened surfaces and to silicone rubber. When using an abrasive medium comprising a mixture of a visco-elastic matrix and abrasive particles, this "bonding" property allows adherence of at least a portion of the
25 matrix to such a surface to provide resistance to abrasion by the particles or grit. This "bonding" property also may be utilized for articles of manufacture such as belts for belt sanders, abrasive pads for manual use, and devices for increasing the abrasion of selected work surface areas--particularly selected work sur-
30 face areas of internal bores.

The invention further deals with selectively masking a work-
piece with a ceramic or the like in order to control surface
finishing by a flowable abrasive. Due to such masking, abrasion
of selected areas of the workpiece may be reduced controllably,
5 or prevented, while normal abrasion is allowed to occur on other
areas of the workpiece.

It is known to extrude a visco-elastic abrasive medium
through workpieces to accomplish abrasive finishing of
selected surfaces of the work, as disclosed in U.S. Patent
10 No. 3,634,973 - McCarty. Other references directed to this
approach are U.S. Patent Nos. 3,802,128 - Minear, Jr., et al.;
3,819,343 - Rhoades; and 3,521,412 - McCarty. The disclosures
of the above patents are hereby incorporated by reference.

It is also known, as in Japanese Utility Model Publication
15 55-53320, to space a work surface opposite from a deformable,
elastic member and force a flowable abrasive mixture there-
between, with the elastic member deforming to reduce flow
restriction caused by the work.

It is also known to hone or lap gears, as in U.S. Patent
20 No. 3,618,272 - Whalen, et al., in which a thickened, flowable
abrasive medium is used. Other references disclosing this same
general approach are U.S. Patent Nos. 3,293,805 - Davis;
3,955,327 - Franco; 2,986,856 - Fehr; and 3,169,349 - Findley.
A meshing (usually driving) relationship is required between
25 two surfaces, whether or not one or both are the work surfaces
to be treated.

It is also known, as in U.S. Patent No. 3,593,410 - Taylor,
to chemically alter the surface of one of a pair of generally
mating die surfaces, to place abrasive grains or grits between
30 the die pair, and to impart relative motion between the die pair
to remove any protuberances from the chemically altered surface.

It is also known, as in Japanese Utility Model Publication 50-29197, to abrade a workpiece cavity by use of a mating mandrel having an elastic, deformable surface attached thereto and abrasives applied to the elastic surface.

5 Other known processes of finishing surfaces employ: vapor blasting, sand blasting, shot blasting, and vibratory finishing. Vapor blasting incorporates an abrasive slurry which is forced against the product at relatively high velocity. The impingement of the abrasive particles on the surface of the product erodes or
10 abrades away the surface. This process has almost no effect on surfaces located interiorly of the product. Sandblasting involves the use of abrasive particles thrown at high speed by compressed air or a mechanical flinger. This process also has little value for interior surface finishing. Shot blasting uses cast iron
15 shot, steel shot, or glass beads at high velocities as in the case of sand blasting. This operation is more nearly a peening over of burrs or the like rather than a clean removal. Vibratory finishing agitates the product in a mixture of abrasive particles, stones, or jacks, and is carried out at low pressure. The more
20 exposed surfaces receive the most action. Here again, interior surfaces receive little or no abrasive effect.

U.S. Patent Nos. 2,799,789 - Wolfskill and 3,247,572 - Munk disclose prior methods of masking of small objects, such as piezoelectric crystals and miniature magnetic cores for micro-
25 circuits, in order that surfaces of the devices may be selectively abraded by the above-mentioned sandblasting, tumbling, shot-peening, or the like. The material used to mask these small objects comprises a lacquer, varnish, paint, ink, or the like which provides a resilient covering having doubtful masking capabilities
30 when used with a flowable, visco-elastic abrasive material.

- 4 -

Also this masking material was required to be diluted to assure "a surface tension of appropriate magnitude so that the resulting coating on the objects pulls away from ... sharp projections and collects on (the) broad surfaces
5 of (the) objects ..."

Further, these patents disclose abrasive processes which do not provide for good abrasion of internal work surfaces or cavities.

The present invention incorporates the use of an abrasive medium having a plastic or semisolid matrix containing abrasive particles distributed substantially uniformly throughout. The purpose of the semisolid matrix is to transport the abrasive particles through or across selected portions of a workpiece being treated in order to permit the abrasive particles to remove up-raised metal and to round or radius corners as it passes, or to otherwise uniformly remove or finish these portions.

Another purpose of the semisolid matrix is to hold the abrasive particles in suspension so that they will be pressed firmly against the workpiece, as taught hereinafter, so that the abrasive effect is at a maximum and is uniformly distributed over the surface or edge being treated.

Another purpose of the semisolid matrix is to provide a relatively firm backing for the abrasive when the medium is under pressure, in order to increase the cutting action of the abrasive against the workpiece portion being treated, while still being plastic enough to flow through or across the product in order to reach all required surfaces and edges. Although abrasion of the workpiece is only accomplished by the abrasive particles which come in contact with it, the other, non-contacting particles, and their flow, are just as important as the particles that actually do the abrading of the workpiece.

It should be noted that a liquid slurry carrying an abrasive material and pumped through the same kind of workpiece as treated by this invention, would not have the required abrasive action nor would it strike all surfaces uniformly. Such a liquid slurry

would require high flow velocity to provide maximum impingement of the abrasive particles against the treated surface. Under such conditions some areas requiring abrasion would receive no abrasion at all.

5 One embodiment of the instant invention is especially useful in polishing mold cavities of complex shapes in which the internal peripheral surface to be worked or polished is of a varying radius. One such workpiece is the internal surface of a plastic injection mold for a telephone receiver. These mold cavities
10 are usually polished manually by a skilled die maker at a time consuming rate of approximately 1-4 hours per square inch of work surface. Additionally, piece-by-piece, manual polishing of these mold cavities is not constantly repeatable, and human error accounts for workpiece wastage. On the contrary, the
15 invention provides a time-wise and materials-wise efficient method and means for repeatably abrading, honing, or polishing such workpieces in an inexpensive manner. By this embodiment, the abrasive medium is displaced positively against and across a portion of a workpiece which is utilized as the displacement
20 chamber or as the displacer, or as both. In this context, the abrasive medium acts as a positively displaced abrading tool. There is no need for engagement, such as meshing, between the opposed surfaces, nor is there a need for mating of these surfaces although, in practice, it may be desirable to use such
25 an arrangement. Further, there is no need to chemically alter the work surface prior to or during the abrading thereof.

Throughout the description of the invention, the term "relative motion" between the opposed surfaces is used to indicate that either or both surfaces may be moved to accomplish positive

displacement of the flowable abrasive medium. Further, this movement may be gyratory, orbital, reciprocatory, or any combination of these, so long as positive displacement of the abrasive medium is accomplished against and across the work portion to be treated
5 in a manner allowing the uniform abrasion offered by a flowable, preferably visco-elastic, abrasive media.

Figures 1-4 are partial cross-sectional views of an internal passageway of a workpiece, illustrating various means of practicing one embodiment of the invention.

10 Figures 5 and 6 are isometric views, partially broken away, illustrating another embodiment of the invention.

Figure 7 is a schematic side elevation of a belt sander incorporating another feature of the invention.

Figure 8 is a partial isometric, with parts broken away,
15 illustrating still another embodiment of the invention.

Figure 9 is a side cross-sectional view of another embodiment and illustrating a reciprocatable mandrel within a mold cavity.

Figure 10 is a side, cross-sectional view illustrating an
20 alternate embodiment of Figure 9.

Figure 11 is a top view taken along the lines 11-11 of Figure 10.

Figures 12-14 are top views depicting various opposed surface profiles and arrangements.

25 Figure 15 is a plan view of another embodiment of the invention.

Figure 16 is a plan view, partially in section, illustrating still another embodiment of the invention.

Figure 17 is an approximate cross-sectional view, as viewed
30 in the direction of arrows 17-17 of Figure 16.

Figure 18 is a front plan view of a machine suitable for use in the invention.

Figures 19-21 are schematic cross-sections illustrating flow of a visco-elastic abrasive medium through a workpiece.

5 Figures 22 and 23 are partial schematic cross-sections of a workpiece to illustrate masking and selective protection of one surface of a workpiece which would be directly subjected to abrasion during treatment of an adjacent portion of the workpiece.

Figure 24 is a schematic cross-section of a workpiece to
10 illustrate masking and protection of surfaces which are indirectly subjected to abrasion during treatment of an adjacent portion of the workpiece.

Throughout the drawings, like parts are indicated by like numbers.

15 Referring to Figure 1, a workpiece 10 having internal bore 12 is provided with a protrusion 14 formed of or coated with silicone rubber or the like and is secured or held in place by any of various means within the skill of the art, opposite from a selected portion of the internal surface of bore 12, to form a
20 restriction. Due to this restriction and the properties of a visco-elastic abrasive medium used in the invention, the internal surface may be selectively reduced, as indicated in phantom lines at 16. Because of the property of bonding to silicone rubber of the matrix of some of the media used in this invention, a surface
25 layer of the matrix, as indicated at 18, adheres strongly to protrusion 14 to further restrict bore 12. It has been found that layer 18 also provides abrasion resistance to silicone rubber.

A change of flow direction of the medium tends to increase the abrasive action at a conjunction of surfaces. Since protrusion 14 is protected from abrasion by layer 18, the increased abrasive action of the medium is directed against the portion of the internal surface of bore 12 which is opposite of protrusion 14. Arrows 20 indicate the flow of the medium without protrusion 14, and phantom-lined arrows 22 indicate the altered flow of the medium due to protrusion 14.

Protrusion 14 may be composed in its entirety of a silicone rubber-like material, as shown in Figure 1, or it may be coated with a layer of silicone rubber-like material. Figure 2 discloses a molded silicone rubber plug 30 which is opposite the selected area of abrasion. Although plug 30 is shown in Figure 2 as protruding into bore 12, it may also be "even" with or slightly "recessed" relative to the internal surface of bore 12, so long as a surface layer 18 of the matrix adheres strongly to the plug so as to provide a restriction of bore 12. In this regard, it should be mentioned that the invention is applicable to increased or directed abrasion for surfaces other than internal bores, such as selected portions of cavities or even external surfaces.

Additionally, as indicated generally at 42 in Figure 3, the material for causing the restriction of the passageway may also be any porous material 40, such as woven fibers or material with a porous surface, such as an oxidized iron or steel, since it has been found that some of the matrices used in the invention adhere strongly to such surfaces also.

Figure 4 illustrates a restrictor 50 for finishing or undercutting a bore 12 peripherally at 13.

Figures 5 and 6 illustrate hand tools such as abrasive pads or blocks, generally indicated at 60, with the abrasive medium

adhered thereto. In Figure 5, substrate 62 is provided with a silicone rubber coating 64 to which visco-elastic matrix 66 adheres. Alternatively, substrate 62 could be silicone rubber material in its entirety, and coating 64 could be eliminated.

5 In Figure 6, a porous substrate 68 is covered with the matrix 66 as by dipping. The various substrates used may have varying degrees of stiffness or flexibility, according to the use intended.

Figure 7 schematically illustrates a porous, or silicone rubber, or silicone rubber coated belt 72 for a portable belt
10 sander 70. A supply reservoir 74 is provided for periodical or continual resupply of a visco-elastic abrasive medium to the work engaging portion of the belt 72. With this arrangement, the useful life of the belt 72 as an abrader is greatly, if not indefinitely, extended.

15 Figure 8 depicts one blade 82 of a turbine 80, the surface of which must be finished to a required tolerance, as by extruding or otherwise passing a flowable abrasive medium between blade 82 and guides 84 of a tooling jig. Prior to the invention, guides 84 were subject to abrasion during the extrusion process, thus caus-
20 ing continuous widening of the gap between guides 84 and blade 82 and reduction in abrasion of subsequently treated blades 82 due to this widening gap. This presented a costly problem in the finishing of workpieces such as blades 82. However, by molding guides 84 of a silicone rubber-like material 86 or coating por-
25 tions 88 of guides 84 with silicone rubber, and by using an abrasive medium which is a mixture of a visco-elastic matrix and abrasive particles, a film of the matrix adheres to the silicone rubber and protects the surfaces of guides 84 such that a reliable, repeatable finishing of a multitude of blades is realized

while using the same tooling jig. Because of the relative in-expense in molding guides 84 from a silicone rubber-like material, they are easily replaceable if eventually abraded out of the required tolerance.

5 The spacing between the work surface and the opposed working surface (protrusion 14 of Figure 1 or guides 84 of Figure 8) is selectable according to such parameters as: matrix viscosity, grit size, work surface finish desired, input energy, and amount of relative displacement normal to the opposed surfaces. This
10 spacing should be at least greater than the diameter of the largest abrasive grit when using a generally non-deformable working surface; and a spacing of at least four times the grit diameter is preferable. Although not necessary, the profiles of the opposed surfaces may be substantially mating in shape.

15 Figures 9-15 disclose alternate embodiments for treating, polishing, or abrading internal and external three-dimensional work surfaces. As with the other embodiments, an abrasive medium comprising a visco-elastic matrix permeated with abrasive particles or grit is used. A preferred abrasive medium for use in
20 the invention has a visco-elastic, rheopectic matrix of silicone bouncing putty (borosiloxane) interspersed with abrasive particles.

 In the embodiment of Figure 9, the abrasive medium is used to treat the internal surface 12 of a mold 10 by utilizing a
25 mandrel 14 having a profile smaller than (and generally mating with) that of the mold cavity. External surface 16 of mandrel 14 is spaced from internal surface 12 of mold 10 to define a gap 22 through and across which the abrasive medium is displaced positively in the general direction of arrows 24 by relative movement
30 between mold 10 and mandrel 14. This relative movement may take

the form of reciprocation, oscillation, rotation, orbital motion, or any combination of these motions of either or both of the mold 10 and mandrel 14. In this particular embodiment, mandrel 14 includes a passage 18 through which the abrasive medium is fed 5 into the cavity as indicated by arrow 20. After a sufficient amount of abrasive medium has been fed into the mold cavity, passage 18 may be sealed before imparting the relative movement between mold 10 and mandrel 14. In Figure 9, mandrel 14 is illustrated as the working displacer formed from or coated with 10 an abrasion-resistant material such as a polyurethane. Alternatively, when using an abrasive medium having a visco-elastic matrix, the working surface may be composed of or coated with a silicone rubber-like material or the surface of the working surface may be roughened or porous such that a portion of the 15 visco-elastic matrix adheres or "bonds" thereto to provide this abrasion resistance. Although Figure 9 illustrates external surface 16 as the working surface and internal surface 12 as the work surface, it should be understood that these roles could be changed such that either or both of the opposed surfaces 12, 16 20 receive treatment by the abrasive medium.

In Figure 10, passageway 18 has been eliminated and a removable cavity sealing member 30 has been added. Sealer 30 and/or mandrel 14 may be raised or removed to allow introduction of the abrasive medium (generally indicated at 40) into the cavity. As 25 may be appreciated by reference to Figures 10 and 11 (Figure 11 is a cross-section in the direction of arrows 11-11 of Figure 10) arrows 32 are meant to indicate relative reciprocatory, rotary, oscillatory, or orbital movement, or any combination thereof, between the mandrel 14 and mold 10.

Figures 12-14 are cross-sections illustrating various profiles of work surfaces 12 and working surfaces 16 which are applicable to practice of the invention. In Figure 13, external surface 12 is the work surface and internal surface 16 is the working surface. It is thought that this substantial likeness in profiles enhances the positive displacement and abrasive action of the medium when relative movement is imparted between the two surfaces.

Figure 15 illustrates another structural embodiment of the invention in which a screw conveyor 50 is rotated about and/or reciprocated along longitudinal axis 52. Surrounding conveyor 50 is a coaxial tubular enclosure 60 comprising an internal surface facing and opposed to the external surface of screw conveyor 50. The edges of flights 54 of conveyor 50 may be spaced from or in rubbing contact with the internal surface of enclosure 60. As in the other embodiments of the invention, either or both the internal and external surfaces may be the work surface and all or selected portions of the working surface may be provided with the abrasion resistance as taught by this invention. Additionally, the conveyor 50 or the enclosure 60, or both, may be tapered or have varying radii and still be within the scope of the invention when the abrasive medium is used for polishing or honing or the like.

In the embodiments of Figures 9-14, it is generally preferred that there is always a gap between the opposed surfaces of sufficient spacing that the largest abrasive grit being used cannot bridge this gap and engage both surfaces simultaneously, and there is no need for the gap to be any smaller when using a visco-elastic matrix as taught by the invention. However, as may be appreciated from Figure 11, working surface 16 may be temporarily deformable by the abrasive grit and the spacing between the work and working

- 14 -

surfaces may be smaller than the largest abrasive grit being used. With such a deformable working surface, any flowable abrasive medium may be used, according to the desired treatment of the work surface.

5 A still further embodiment of the invention is disclosed in Figures 16 and 17, in which workpiece 90 has a cavity 92 which is to be polished, honed, or the like by means of the abrasive medium of the instant invention. In this embodiment, a plurality of tubes 94 are loosely held together such that they may conform
10 substantially to the cavity 92, as by assuming various vertical heights according to engagement of their lower ends with cavity 92. Having substantially conformed to this surface, they are then tightly held or clamped together as by metal strap 96 and adjustable machine screw 97 such that they may be removed from
15 cavity 92 while still retaining the general shape thereof at their lower ends. Although Figure 17 discloses tubes 94 to be of varying diameters, it is contemplated also that all of the tubes 94 may have the same general diameters. In implementing this embodiment, the clamped together tubes are then again lowered into
20 cavity 92 such that they are slightly spaced from the surface of cavity 92 and workpiece 90 is moved in a plane generally perpendicular to the vertical axes of tubes 94 by imparting orbital, reciprocating, rotational, or any combination of these movements to a table or the like upon which workpiece 90 is mounted. Al-
25 ternatively, workpiece 90 could remain stationary with the same general type of motion imparted to the clamped together group of tubes 94. It is also contemplated that both the workpiece 90 and clamped together tubes 94 could have motion imparted thereto. The purpose of the tubes 94 is to provide flow passages for the abra-
30 sive medium of the instant invention. The abrasive medium is

caused to flow, as by an applied pressure through the tubes 94 into the gap between the lower ends of tubes 94 and cavity 92. Although tubes 94 are illustrated as having circular cross-sections, various other cross-sections, including rectangular and triangular, are contemplated. Additionally, relative vertical reciprocation between the clamped tubes 94 and workpiece 90 may be imparted. Although Figure 16 illustrates tubes 94 as only partially covering the internal surface of cavity 92, it is contemplated that a sufficient number of tubes 94 may be provided such that substantially the entire surface of cavity 92 is covered by tubes 94. Although Figure 16 discloses this embodiment as used upon a generally concave work surface, it is also contemplated that a generally convex, or outwardly protruding, work surface may be treated using the same general concept. Further, when more than one cavity of the same three-dimensional shape is to be abraded, polished, honed, or the like, such an arrangement of tubes 94 may be permanently attached together as by braising, adhesives, or the like.

Figure 18 illustrates a machine suitable for imparting relative motion between opposed surfaces during machining of at least one of the surfaces while using a visco-elastic, preferably rheopectic, abrasive medium. The machine includes two vertically opposed platens 102 and 104, either or both of which are provided with means for imparting reciprocating motion in the vertical direction and orbiting, gyrating, oscillating, reciprocating, and the like motions in a generally horizontal direction. Platen 104 has workpiece 106 attached thereto, with workpiece 106 having a work surface 105 to be machined. Fastened to platen 102 is a complementary model 103 which is generally a mirror image of work surface 105. Rather than imparting the relative motion to platens 102 and 104, suitable devices (not shown) may be attached

to platens 102 and 104, with these suitable devices supporting complementary model 103 and workpiece 106 and imparting the relative motion therebetween. Devices for imparting relative motion between two surfaces are generally known to be old in the art and are not, per se, the invention. A visco-elastic abrasive medium is fed from a supply 108 via supply tube 110 to the interface between surfaces 103 and 105. Working surface 103 is formed from a plurality of tubes or is provided with pre-drilled holes through which the abrasive medium is transported to the interface. In operation, top platen 102 is lowered into contact with platen 104 according to the accepted method in such machines. Relative motion commences with the two platens 102, 104 slowly being forced further toward each other as the work surface 105 is machined. During the course of this operation, the abrasive medium is replaceable by advancing refeed piston 112, with the older, used medium simply being forced out of the work surface 105 and onto platen 104 for collection by the operator of the machine.

It should be noted that the opposed surfaces 103, 105 need not be exact complements as suggested by the figure. Rather, by using a visco-elastic, rheopectic abrasive medium, the working surface needs to be only a rough approximation of the work surface. Use of such a machine combines the full, three-dimensional machining capabilities of orbital abrasion with the uniform abrasion offered by a visco-elastic abrasive medium.

Previously, the basic technique of having two opposed surfaces undergo relative motion while in contact relied upon a "working" surface being embedded with an abrasive grit to form, polish, or in some way machine the work surface. Machining methods utilizing visco-elastic abrasive mediums previously achieved the abrasive action only by hydraulically forcing the

media through or across the work surfaces. In contrast, the machine and method of use described above and illustrated in Figure 18 allows gyrating, orbiting, reciprocating, or any combination of these motions to be imparted between opposed surfaces 5 while using a visco-elastic abrasive medium and thus facilitating a smooth and uniform abrasion of a workpiece.

In certain instances, a workpiece will include areas that must be abraded or machined and which lie directly adjacent to other areas that, due to critical tolerances, must be left intact 10 and untouched by the abrasive medium. Prior to another embodiment of this invention, it was necessary to protect certain areas of the workpiece from abrasion by means of fixtures and mandrels designed specifically for the workpiece. These fixtures and mandrels represented a tooling cost, in both time and money, 15 beyond that of the actual abrasive flow machining. Additionally, particular areas of a workpiece were very difficult, if not impossible, to protect from abrasion during such flow machining. To overcome these vast difficulties, the instant invention also involves masking of these particular areas of a workpiece in order 20 to selectively protect and abrade various workpiece portions as explained hereinafter.

Referring to Figure 19, abrasive grains 120 are carried in a semi-solid matrix (not shown) and forced to flow across or through a workpiece 122. By way of example, a particular abrasive 25 grain 121 contained in the matrix cuts into or abrades workpiece 122 to remove a small, yet predictable, portion of the workpiece surface as the abrasive medium is caused to flow in the general direction of arrow 124. Thousands of these particles 120 act together to evenly abrade the surfaces of a workpiece. In this 30 respect, arrow 130 illustrates the force of the abrasive grain

generally parallel to flow direction 124 and arrow 132 illustrates an angled force that determines the depth of cut of the abrasive grain 121 into the workpiece. Angled force 132 is determined by the restriction of the passageway through the workpiece and the pressure with which the abrasive medium is forced to flow. As seen in Figure 20, the abrasive medium should be made to flow evenly through the passageway to uniformly polish passageway surfaces 126, with the evenness of flow indicated by parallel lines 128. However, when it is desired to radius an entrance to a passageway, as at 134, then the flow of the abrasive medium should be faster through the center of the passageway than at the edges thereof, as illustrated by curved flow lines 129, wherein edges 134 at the passageway entrance are abraded more than surfaces 126 of the passageway.

However, there are instances in which particular edges or surfaces of a workpiece must be abraded or machined while other surfaces lying directly adjacent thereto must not be machined because of critical tolerances. As applied to Figure 21, this would be a situation where edges or corners 134 must be radiused but the distance between adjacent surfaces 126 must be held constant. Accordingly, surfaces 126, although directly in the flow path of the abrasive medium, must not be abraded. In this embodiment of the invention, a ceramic mask is applied to the area to be protected, such as surfaces 126 of Figure 21. After the mask cures, the workpiece is machined by a flowable abrasive medium. When subjected to the abrasive action, the mask remains relatively intact to protect surfaces 126 while surfaces 134 are subjected routinely to the machining operation. One manner in which such selective machining may be accomplished will be better understood by reference to Figures 22 and 23. In Figure 22, a

workpiece 140 has a passageway similar to that illustrated in Figure 20 with an edge or corner 142 at the entrance to the passageway which needs to be radiused or abraded while surface 148 of the passageway must be left unabraded. Accordingly, a ceramic mask 146 is applied to surface 148 and, due to the natural characteristics of the abrasive flow, or other abrading process to provide more abrasive action at the corner 142 than along the remaining portion of surface 148. Although ceramic mask 146 resists abrasion during machining of the workpiece by this abrasive process, some of mask 146 will be removed abrasively such that corner 142 will be radiused, as indicated by phantom lines, at 144 in Figure 22. Accordingly, there is a smooth blend between radius 144 and unabraded surface 148, as illustrated in Figure 23. After the machining process, mask 146 is removed by soaking the workpiece in a detergent suitable for removal of the ceramic coating.

There are other instances, as in Figure 24, in which the corners and internal walls of a passageway (generally indicated as 152) must be machined while other surfaces 150 which are indirectly subjected to the abrasive action of the flowable abrasive medium should not be machined. Surfaces 150 are sometimes very difficult, if not impossible, to protect from such abrasive action. By the instant invention, it is only necessary to apply the ceramic mask 146 to surface 150 in order to provide the necessary protection.

Other uses for this embodiment of the invention include the prevention of abrasion where a special finish has been placed on the surface or where the abrasive medium would leave a cosmetically unacceptable mark on the workpiece. As may be appreciated from

the above description, the mask provides protection of workpiece areas which are subjected to both direct and indirect flow machining. This protective mask could also be used in vibratory, spindel, tub, barrel, or gyro finishing processes, all of which use an abrasive medium to finish a workpiece. The mask may be comprised of ceramic, silicone, or similar substances which may be painted or dipped onto critical areas to protect them, while allowing other areas of a workpiece to be abraded normally.

Typical parameter ranges for the embodiments of Figures 9-14, 10 and 18 include: grit sizes of 6 microns to 16 mesh, gap distances of 0.002-0.500 inches, time of treatment of 5-60 minutes, vibrations per minute of 20-2,000, and amplitude of vibration of 0.025-0.500 inches. Specifically, after substantially filling the gap with a rheopectic abrasive medium, the mandrel of Figure 9 could be operated at 500 vibrations per minute with an amplitude of 0.05 inches for 5 minutes and a gap of 0.005 inches would be sufficient for a grit size of 10 microns.

It is preferable that the plastic carrier matrix have sufficient body at moderate pressure and low velocity to press the abrasive particles against the work surface with sufficient force to produce the result desired. One mixture successfully used in the invention is MV70 Extrude-Hone media, comprising 50% by volume of silicon carbide abrasive grit and 50% by volume of silicone bouncing putty (borosiloxane) carrier (matrix) having a ratio of approximately 2:1 by weight.

By definition, silicone bouncing putty (borosiloxane) exhibits many of the characteristics of a fluid. Under ^{suddenly applied} pressure it becomes less flowable and more like a solid. It conforms exactly to the shape of whatever confines it and this helps in abrading

3082

intricate shapes and details. It should be noted that silicone bouncing putty (borosiloxane) is particularly useful in the invention as it is well known that this material becomes harder when subjected to sudden shear force such as when squeezed in the gap
5 between the opposed surfaces as they are moved relative to one another. This increased stiffness enhances abrasion of the work-piece by holding the abrasive particles more firmly in place and transferring the driving force of the working member to the abrasive grains at the work surface.

10 A non-rheopectic abrasive medium suitable for use in some situations is that described in U.S. Patent No. 3,819,343 - Rhoades.

This invention may be utilized to hone or abrade machined parts, die castings, forgings, sand castings, investment castings
15 and extruded shapes. It is applicable to all materials such as steel, aluminum, brass, bronze, plastics, glass and other compositions and materials as needed.

Obviously, the abrasive used in the carrier matrix will be varied to suit the job. A satisfactory abrasive to use in working
20 on steel is boron carbide (BC) which is readily obtainable from the Norton Company in standard grit sizes. Another abrasive which is useful for many applications is aluminum oxide. Other abrasives might include diamond dust, silicon carbide, rouge, corundum, garnet, alundum, glass or, in some unusual operations,
25 softer material such as fiber or shell material. Commonly, the abrasive will vary from about 2 to 4 pounds of abrasive particles per pound of the matrix material.

The above-mentioned visco-elastic honing mediums act as a surface abrading tool and are unique for the reason that the
30 abrasive grit is held or contained in a random repositioning

arrangement in a plastic matrix. The grain particles in use in the process of this invention are sharp until the sum of all points or edges have been exposed many times, as opposed to the traditional concept of an abrasive "stone" or lap wherein the
5 grain particle is fixed and presents one cutting point or edge which is maintained until dulling causes removal by means of a dressing operation.

The fastest cutting action, which is also consistent with the most uniform results, occurs when the medium exhibits an oily
10 nonadhering contact with the work surface. It would appear that when in this condition the medium has the greatest opportunity to pass through the gap at a constant cross-sectional pace. This is contrary to a fluid flow which is greatest through the center and supposedly "zero" along the wall.

15 It is to be understood that the present invention is not limited to the preferred embodiments disclosed herein, and that many modifications in construction, arrangement, use and operation are possible within the true spirit of the invention. Accordingly, the present invention is to be considered as including all
20 such modifications and variations coming within the scope of the appended claims.

- 23 -

CLAIMS

1. A method of abrasive treatment of a work surface having a profile, said method comprising the steps of:
forming a backing surface having a profile generally the same as said work surface;

5 coating said backing surface with an abrasion resistant material;

facing said backing surface opposite from and in spaced relation to said work surface to form a gap therebetween; and

10 introducing a visco-elastic, abrasive medium under pressure into said gap and guiding said medium against and across said work surface and abrading said work surface, said medium comprising a mixture of a visco-elastic, rheopectic matrix and abrasive particles.

15 2. A method of treating a profiled work surface by abrasion comprising the steps of:

forming an abrasion resistant material to provide a backing surface having a profile at least a portion of which is generally the same as said work surface profile;

20 facing said backing surface opposite from and in spaced relation to said work surface to form a gap therebetween; and

- 24 -

introducing a visco-elastic, abrasive medium under pressure into said gap; bonding a portion of said medium to said material and reducing abrasion of said backing surface; and guiding with said backing surface and
5 bonded medium, at least a portion of said medium which is not bonded to said backing surface against and across said work surface during said treatment.

3. A method as in claim 1, wherein said abrasion
10 resistant material is a polyurethane.

4. A method as in claim 3, wherein said matrix is a borosiloxane putty. .

5. A method for protecting a wear surface which is subjected to abrasion by a flowable, visco-elastic, abrasive medium during abrading of a work surface by
15 said medium comprising the steps of:

applying a silicone rubber-like material to said wear surface; and

bonding a portion of said medium to said material
20 during abrading of said work surface with said abrasive medium.

6. A method for protecting a wear surface which is subjected to abrasion by a flowable, visco-elastic, abrasive medium during abrading of a work surface by
25 said medium comprising the steps of:

applying a porous material to said wear surface; and
bonding a portion of said medium to said porous
material during abrading of said work surface with said
abrasive medium.

- 5 7. A method of attaching a visco-elastic, abrasive
medium to a backing comprising the steps of:

providing at least an outer surface portion of said
backing with a silicone rubber-like material; and

- 10 applying said medium to said silicone rubber-like
material; whereby said medium is bonded to said silicone
rubber-like material.

8. A method of attaching a visco-elastic abrasive
medium to a backing comprising the steps of:

15 providing at least an outer surface portion of said
backing with a porous material; and

applying said medium to said porous material such
that said medium is bonded to said porous material.

- 20 9. A method of making an abrasive pad comprising the
steps of:

providing a porous substrate; and

applying a visco-elastic rheopectic abrasive medium
to said porous substrate to bond said medium to said
substrate.

10. A method of making an abrasive pad comprising the steps of:

coating a substrate with a silicone rubber-like material; and

5 applying a visco-elastic abrasive medium to said material to bond said medium to said substrate.

11. A method of restricting the flow of a visco-elastic, abrasive medium through a passageway having an internal surface, comprising the steps of:

10 providing at least a portion of said internal surface with a silicone rubber-like material; and

feeding said medium against and across said portion whereby a portion of said medium is bonded to said material and forms a restriction in said passageway.

15 12. A method as in claim 11 wherein a portion of said internal surface which is not provided with said material and is in opposed, facing relation to said material is a work surface, and further comprising the steps of:

20 directing said medium by said restriction against said work surface; and

treating said work surface with said medium.

13. A method as in claim 12, and further comprising the step of:

continuing said treating for time sufficient to form a cavity in said work surface.

14. A method of treating a selected, generally concave portion of an internal surface of a passageway with a visco-elastic abrasive medium, comprising the steps of:

5 providing a silicone rubber-like material within said passageway in opposed, facing relationship to said selected portion;

feeding said abrasive medium into said passageway and against and across said material;

bonding a portion of said medium to said material;

restricting said passageway at said material with said bonded medium; and

abrading said selected portion with a portion of the medium which is not bonded to said material and is fed through said restriction.

15. A method of reducing a selected portion of the internal surface of a passageway comprising the steps of:

20 providing an abrasion resistant portion in said passageway spaced from and in facing opposition to said selected portion to form a restriction of said passageway opposite said selected portion;

feeding a flowable abrasive medium into said passageway and past said restriction;

25 increasing the working of said abrasive medium on

said selected portion by said restriction; and
reducing said selected portion due to said increased
working.

16. A method as in claim 15, wherein said medium is a
5 visco-elastic abrasive medium.

17. An apparatus for abrading a work surface, comprising:
a flowable abrasive medium for abrading said work
surface during flow of said medium against and across
said work surface;
10 guide means spaced from and in facing opposition to
said work surface and having a portion engageable by
said medium for guiding said medium against and across
said work surface during said abrading; and
protection means for resisting abrasion of said
15 guide means by said medium.

18. An apparatus as in claim 17, wherein said protection
means comprises:
an abrasion resistant polyurethane material; and
at least a portion of said guide means is formed
20 from said polyurethane material, or wherein said
protection means comprises:
an abrasion resistant coating on said portion of
said guide means engageable by said medium.

19. An apparatus as in claim 18, wherein the protection means comprises an abrasion resistant coating and further comprising:

means for supplying said abrasion resistant coating
5 to said guide means continuously.

20. An apparatus as in claim 18, wherein the protection means comprises an abrasion resistant coating and further comprising:

means for supplying said abrasion resistant coating
10 periodically to said guide means.

21. An apparatus as in claim 17, wherein said abrasive medium comprises:

a mixture of a visco-elastic matrix and abrasive particles.

15 22. An apparatus as in claim 21, wherein said matrix is a visco-elastic, rheopectic matrix.

23. An apparatus as in claim 21, wherein said protection means comprises:

said guide means having at least said medium
20 engaging portion comprising a means for bonding a portion of said matrix thereto.

24. An apparatus as in claim 23, wherein said bonding

- 30 -

means comprises:

a silicone rubber-like material, or wherein said

bonding means comprises:

a porous surface.

5 25. An apparatus for abrading a work surface, comprising:
a substrate having a bonding area; and
a visco-elastic abrasive medium bonded to said
substrate at said bonding area.

26. An apparatus as in claim 25, wherein said medium is
10 a visco-elastic, rheopectic abrasive medium.

27. An apparatus as in claim 25, wherein said substrate
is porous over at least a portion of said bonding area.

28. An apparatus as in claim 25, wherein at least a
portion of said bonding area is a silicone rubber-like
15 material.

29. An apparatus for abrasive treatment of a selected
portion of an internal surface by flow of a flowable
abrasive medium against and across said selected
portion, said apparatus comprising:

20 means for increasing the working of said medium on
said selected portion such that said medium is caused to
reduce said internal surface at said selected portion.

- 31 -

30. An apparatus as in claim 29, wherein said means for increasing said working comprises:

means for restricting the flow of said medium past said selected portion.

5 31. An apparatus as in claim 30, wherein said medium comprises a mixture of a visco-elastic matrix and abrasive particles and said means for restricting the flow of said medium comprises:

build-up means, spaced from and in facing opposition
10 to said selection portion, for engagement by said medium flow such that a portion of said matrix bonds to said build-up means and restricts the flow of said medium past said selected portion.

32. An apparatus as in claimed 31, wherein said build-up
15 means comprises:

a porous material, or wherein said build-up means comprises:

a silicone rubber-like coating, or wherein said build-up means comprises:

20 a formed silicone rubber-like plug.

33. An apparatus as in claim 31, wherein said matrix comprises a visco-elastic, rheopectic matrix.

34. A method for treating a workpiece to abrade the surface or edges thereof, comprising the steps of:

providing opposed surfaces in facing, spaced relationg to provide a gap therebetween, at least one of
5 said opposed surfaces comprising a work surface to be treated;

introducing a visco-elastic abrasive medium into said gap;

imparting relative motion between said opposed
10 surfaces and working said medium positively against nd across said opposed surfaces and abrading at least said work surface.

35. A method as in claim 34, and further comprising the step of:

15 imparting relative orbital motion between said opposed surfaces to positively work said medium against and across said work surface, or

imparting relative reciprocal motion between said opposed surfaces along a line of reciprocation to
20 positively work said medium agains and across said work surface, or importing relative rotational motion between said opposes surfaces to positively work said medium against and cross said work surface.

36. A method as in claim 35, wherein relative reciprocal
25 motion is provided and further comprising the step of:

- 33 -

varying the angle of said line of reciprocation relative to an instantaneous point on said work surface to vary the positive work of said medium.

37. A method as in claim 34, and further comprising the
5 step of:

abrading both said opposed surfaces, or further comprising the step of:

confining said medium in said gap during said abrading, or further comprising the step of:

10 introducing more of said medium into said gap to replace medium displaced from said gap during said treatment.

38. A method as in claim 34, wherein at least one of said opposed surfaces comprises a working surface not to
15 be treated by said abrasive medium, said method comprising the further step of:

providing at least a portion of said working surface with means for resisting abrasion.

39. A method as in claim 38, wherein said means for
20 resisting abrasion comprises:

coating said working surface portion with a polyurethane, or forming said working surface portion of a polyurethane.

40. A method as in claim 38, wherein said abrasion resisting means comprises a portion of said abrasive medium, and said method further comprises the steps of:

roughening said working surface portion;

5 contacting said working surface portion with said abrasion medium; and

 bonding said abrasive medium portion to aid roughening during said contact, or the steps of:

10 providing said working surface with a porous material;

 contacting said working surface portion with said abrasive medium portion; and

 bonding said abrasive medium portion to said porous material during said contact, or the steps of:

15 coating said working surface portion with a silicone rubber-like material;

 contacting said silicone rubber-like material with said abrasive medium portion; and

20 bonding said abrasive medium portion to said silicone rubber-like material during said contact, or the steps of:

 forming said working surface portion from a silicone rubber-like material;

25 contacting said silicone rubber-like material with said abrasive medium portion; and

 bonding said abrasive medium portion to aid silicone rubber-like material during said contact.

- 35 -

41. An apparatus for abrasive treatment of a work surface, comprising:

means for abrading said work surface when positively displaced against and across said work surface, said
5 abrading means comprising a visco-elastic matrix having abrasive grit interspersed therein;

opposed surfaces spaced to define a gap therebetween for reception of said abrading means, at least a portion of at least one of said opposed surfaces comprising said
10 work surface to be treated, and said gap defining a displacement chamber for said abrading means;

means for introducing said abrading means into said gap; and

means for imparting relative motion between said
15 opposed surfaces and positively working said abrading means against and across said work surface for abrasion thereof.

42. An apparatus as in claim 41, wherein said matrix further comprises:

20 a visco-elastic, rheopectic material.

43. An apparatus as in claim 41, wherein both said opposed surfaces comprise work surfaces to be treated by said abrading means.

44. An apparatus as in claim 41, wherein at least a

- 36 -

portion of one of said opposed surfaces comprises a working surface, said grit has a largest grit size, and said apparatus further comprises:

5 said gap being greater than said largest grit size, such that said working surface engages said grit with said work surface indirectly via said matrix.

45. An apparatus as in claim 41, wherein at least a portion of one of said opposed surfaces comprises a working surface, said grit has a largest grit size, and
10 said apparatus further comprises:

 said gap being at least as small as said largest grit size, such that said working surface engages said grit with said work surface directly.

46. An apparatus as in claim 45, wherein said working
15 surface further comprises:

 an abrading means engaging surface comprising a temporarily deformable, abrasion resistant elastomer.

47. An apparatus as in claim 46, wherein said elastomer
 comprises:

20 a polyurethane.

48. An apparatus as in claim 41, wherein said surface which is not said work surface comprises a working surface of a displacer, and said working surface further

comprises:

means for resisting abrasion.

49. An apparatus as in claim 48, wherein said abrasion
resisting means comprises:

5 an abrasion resistant polyurethane.

50. An apparatus as in claim 49, wherein said displacer
is formed from said polyurethane, or wherein said
working surface comprises:

a coating of said polyurethane on said displacer.

10 51. An apparatus as in claim 48, wherein said abrasion
resisting means comprises:

means for bonding a portion of said matrix to said
displacer and resisting abrasion of said working surface
by said grit.

15 52. An apparatus as in claim 51, wherein said bonding
means comprises:

a roughened working surface, or wherein said bonding
means comprises:

a porous working surface, or wherein said bonding
20 means comprises:

a silicone rubber-like working surface.

53. An apparatus as in claim 58, wherein said bonding

- 38 -

means comprises the rubber-like working surface and wherein said displacer is formed of silicone rubber-like material.

54. An apparatus for abrasive treatment of a work
5 surface, comprising:

a medium mover comprising a mandrel and generally helical-shaped flights and having an external surface;

a confiner coaxial with and surrounding at least a portion of said medium mover along said longitudinal
10 axis thereof and having an internal surface;

at least one of said external and internal surfaces comprising said work surface to be treated;

an abrasive medium comprising a visco-elastic matrix material having abrasive grit interspersed therein;

15 means for introducing said medium between said internal and external surfaces; and

means for imparting relative motion between said medium mover and said confiner to positively work said medium against and across said work surface for abrasion
20 thereof.

55. An apparatus as in claim 54, wherein said matrix comprises:

a visco-elastic, rheopectic material.

56. An apparatus as in claim 54, wherein said surface

which is not said work surface comprises a working surface of abrasion resistant material.

57. An apparatus as in claim 56, wherein said abrasion resistant material is a polyurethane.

5 58. A method for abrading a three-dimensional work surface with a flowable abrasive medium, comprising the steps of:

providing a plurality of tubes for directing said medium to said work surface;

10 grouping said tubes loosely together and engaging said work surface with one end of each of said tubes such that a bottom of said grouping generally conforms to a profile of said work surface;

securing said grouping together and fixing each of
15 said tubes relative one to the other;

spacing said bottom from said work surface to provide a gap;

introducing said medium through said tubes into said gap; and

20 imparting relative motion between said grouping and said work surface such that said medium is worked across and in engagement with said work surface.

59. An apparatus for abrading a three-dimensional work surface with a flowable abrasive medium, comprising the

steps of:

a plurality of tubes for directing said medium to
said work surface;

means for grouping said tubes loosely together and
5 engaging said work surface with one end of each of said
tubes such that a bottom of said grouping generally
conforms to a profile of said work surface;

means for securing said grouping together and fixing
each of said tubes relative one to the other;

10 means for spacing said bottom from said work surface
to provide a gap;

means for introducing said medium through said tubes
into said gap; and

means for imparting relative motion between said
15 grouping and said work surface such that said medium is
worked across and in engagement with said work surface.

60. A method of abrading a workpiece selectively, said
method comprising the steps of:

applying a ceramic material selectively on said
20 work-piece;

curing said ceramic material;

masking a first portion of said workpiece with said
ceramic material to prevent abrasion of said first
portion;

25 masking a second portion of said workpiece with said
ceramic material to reduce abrasion of said second

portion;

forcing a visco-elastic, rheopectic, abrasive medium against and across said workpiece;

abrading a third portion of said workpiece and said
5 ceramic material masking said second portion to provide a smooth transition between said second and third portions; and

removing all remaining ceramic material from said workpiece.

10 61. A method of abrading and protecting selected portions of a workpiece, comprising the steps of:

applying a ceramic material selectively onto a first portion of said workpiece;

curing said ceramic material and masking said first
15 portion to reduce abrasion of said first portion by an abrasive treatment; and

subjecting said workpiece to said abrasive treatment and abrading a second portion of said workpiece, such that said first portion is subject to a lesser degree of
20 abrasion than said second portion.

62. A method of abrading and protecting selected portions of a workpiece, comprising the steps of:

applying a ceramic material selectively onto a first portion of said workpiece;

25 curing said ceramic material to prevent abrasion of

said first portion by an abrasive treatment; and

subjecting said workpiece to said abrasive treatment and abrading a second portion and preventing abrasion of said first portion.

5 63. A method as in claim 61, wherein said abrasive treatment comprises the step of:

forcing a visco-elastic, abrasive medium against and across said workpiece.

64. A method of abrading and protecting selected
10 portions of a workpiece, comprising the steps of:

applying an abrasion resistant material onto a first portion of said workpiece;

curing said abrasion resistant material to bond said material to said first portion;

15 subjecting said workpiece to abrasive treatment with a visco-elastic abrasive medium and abrading a second portion of said workpiece and protecting said first portion from abrasion by said medium.

65. A method as in claim 64, and further comprising the
20 step of:

abrading an edge of said first portion to a lesser degree than said second portion is abraded such that a smooth transition is provided between said first and second portions.

- 43 -

66. A method as in any of claims 2, 5 to 11, 14, 15, 34, 61, or 65, wherein said medium is a visco-elastic, rheopectic abrasive medium.

67. A method for abrading and protecting a workpiece
5 comprising the steps of:

applying an abrasion-resistant material onto the surfaces of a workpiece to be abraded and protected
subjecting the workpiece to abrasive treatment so
that more abrasive action occurs at selected areas, such
10 as corners and progressively less occurs at adjacent and other areas;

continuing the abrasive treatment until at selected areas the applied abrasive resistant material is abraded away and these areas of the workpiece itself are
15 abraded, such as corners being rounded; yet other selected areas of the workpiece have not seen sufficient abrasive action to fully remove the applied abrasive resistant material and consequently not abrading these areas of the workpiece itself at all; and between these
20 areas providing a smooth uniform transition;

subsequently removing the applied abrasion resistant material remaining on the workpiece by other means.

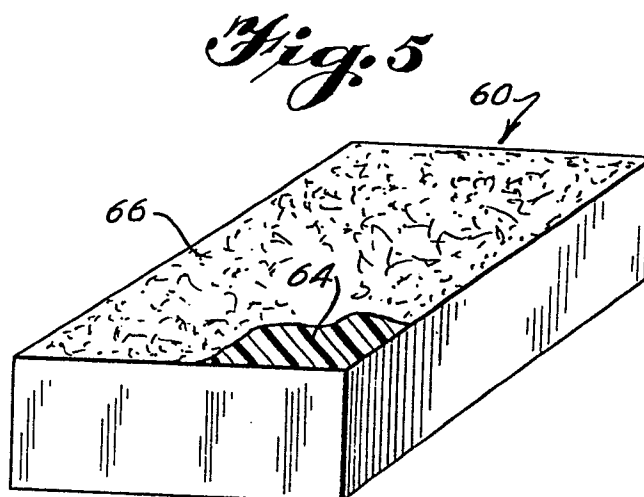
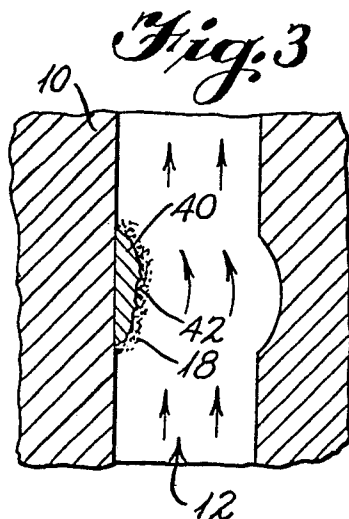
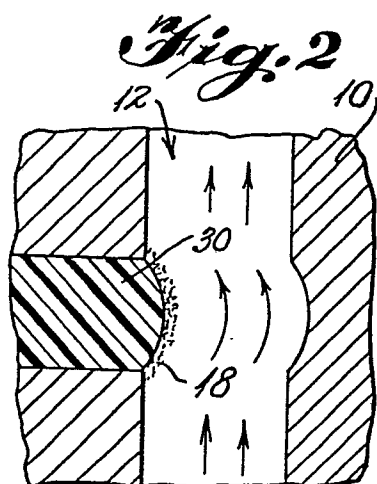
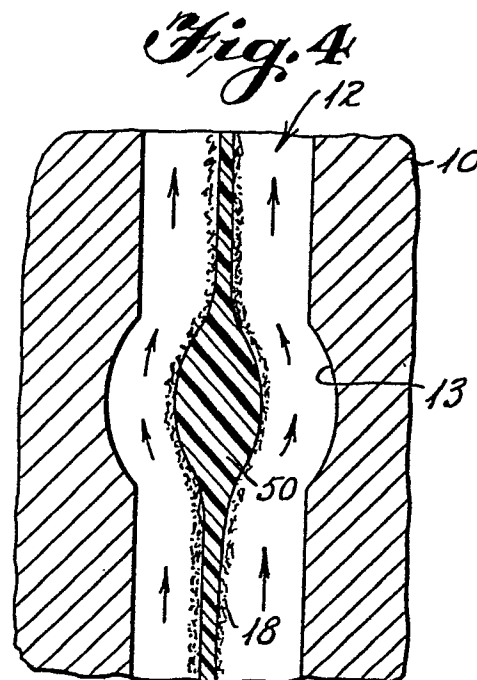
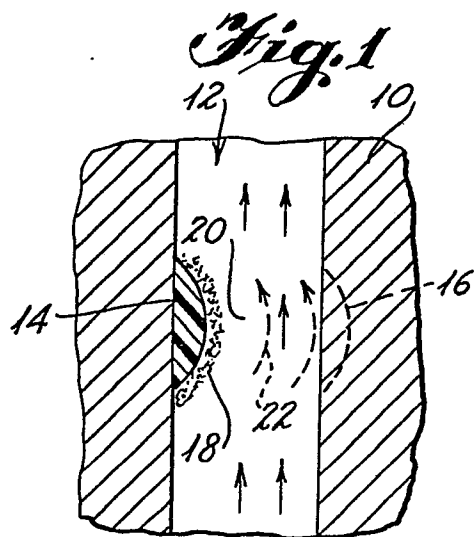


Fig. 6

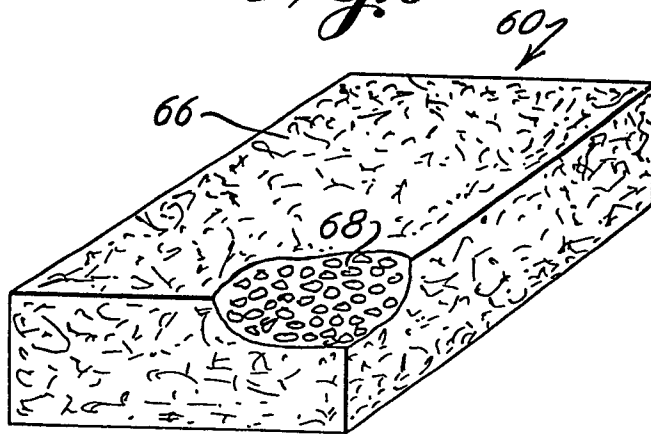


Fig. 7

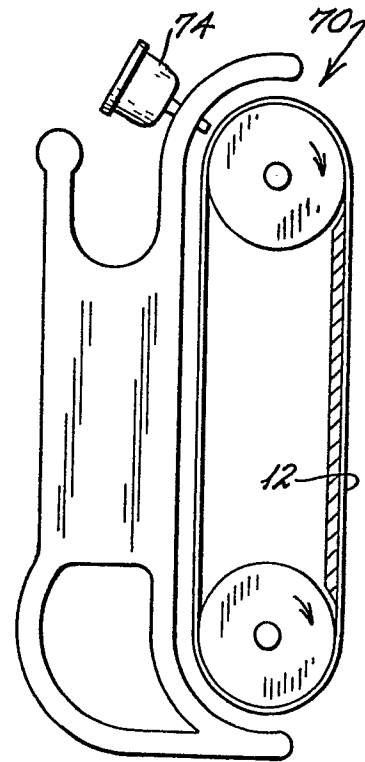


Fig. 9

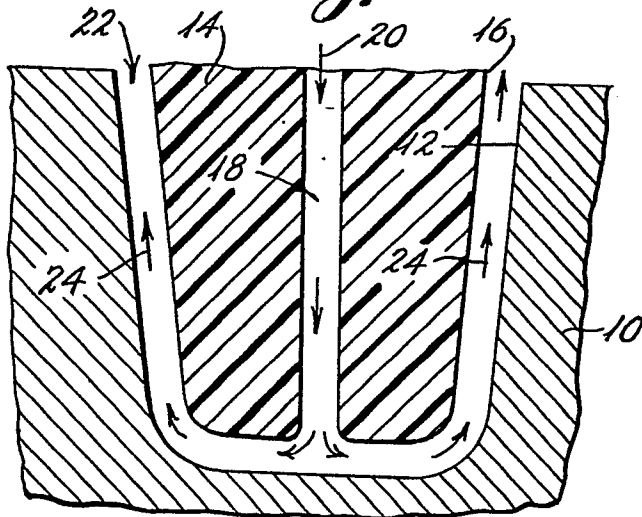


Fig. 8

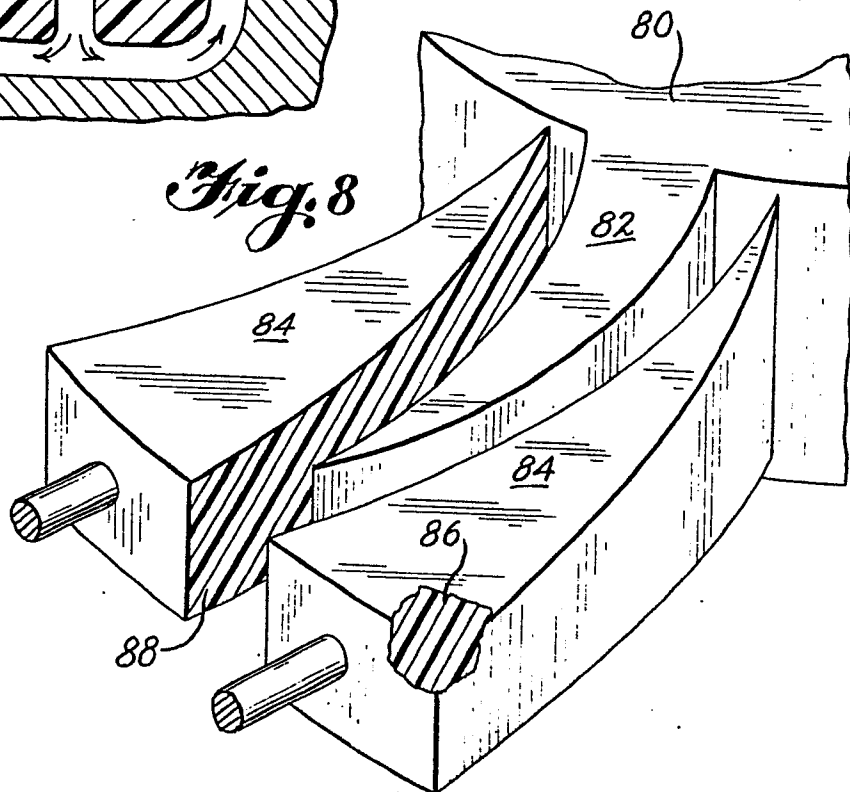


Fig. 10

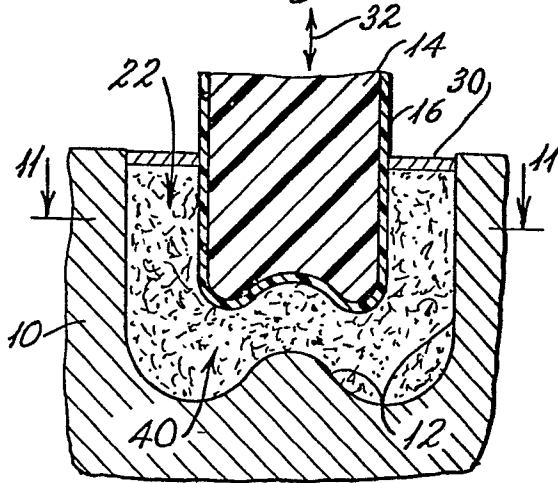


Fig. 11

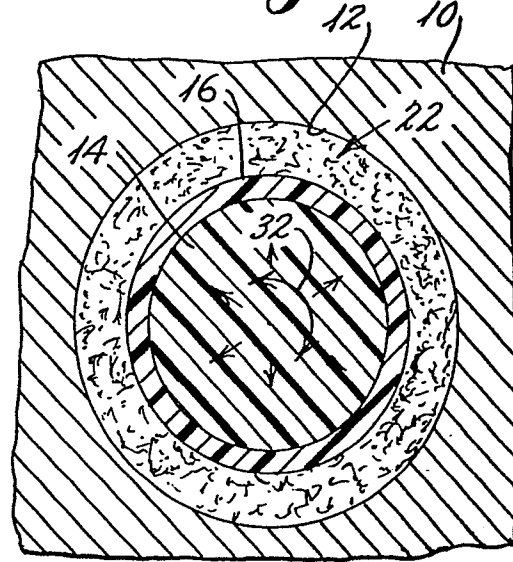


Fig. 12

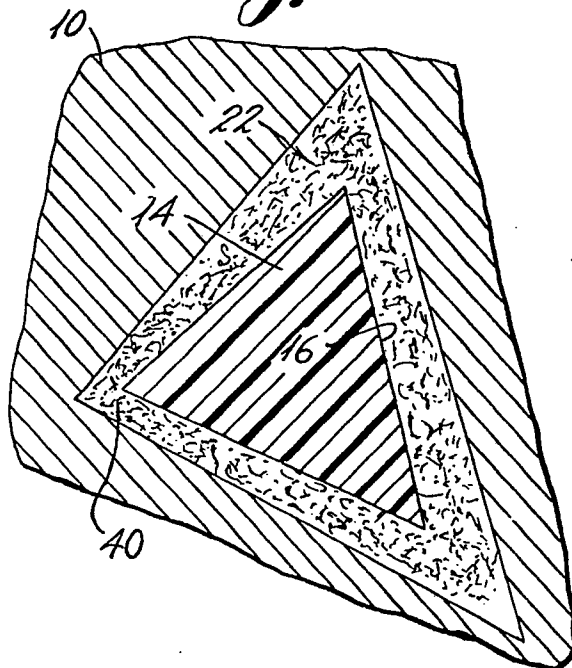


Fig. 13

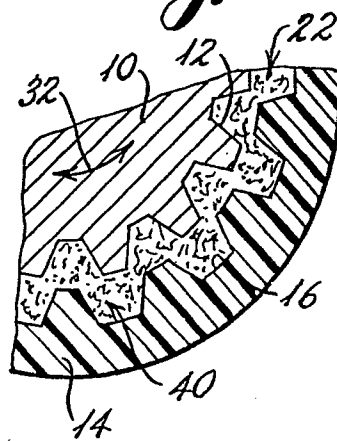


Fig. 14

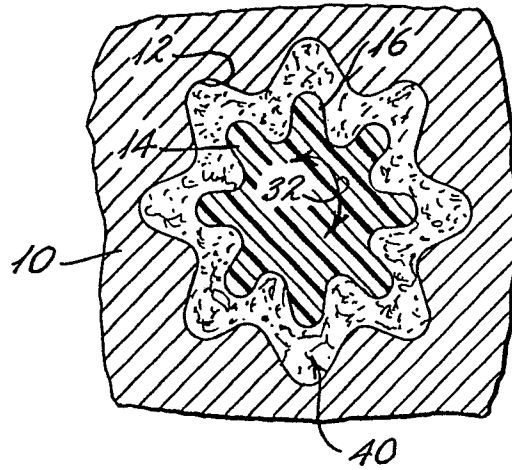


Fig. 15

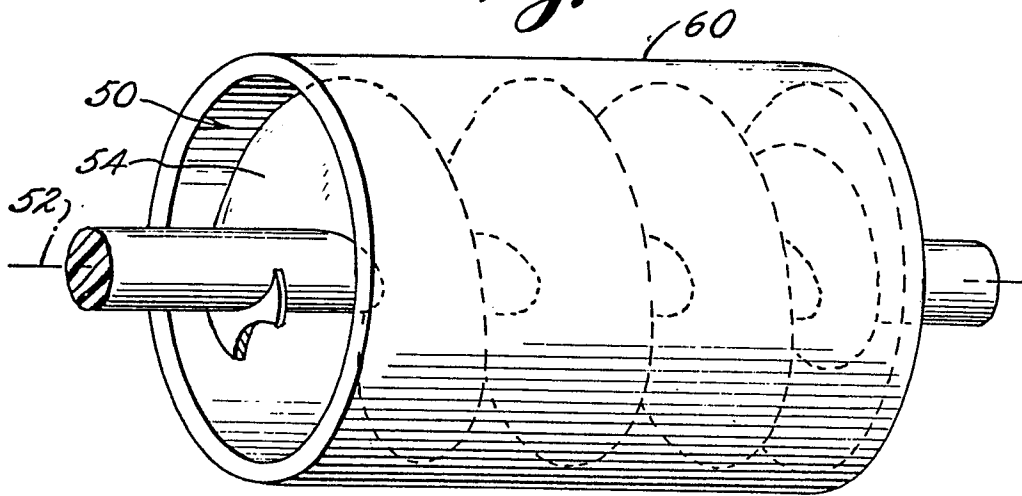


Fig. 16

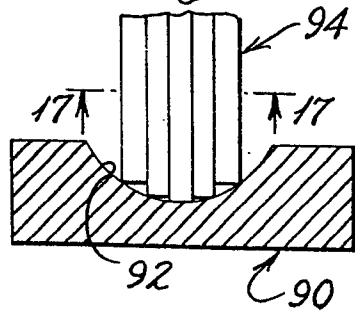


Fig. 17

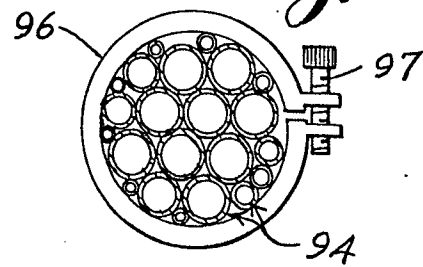


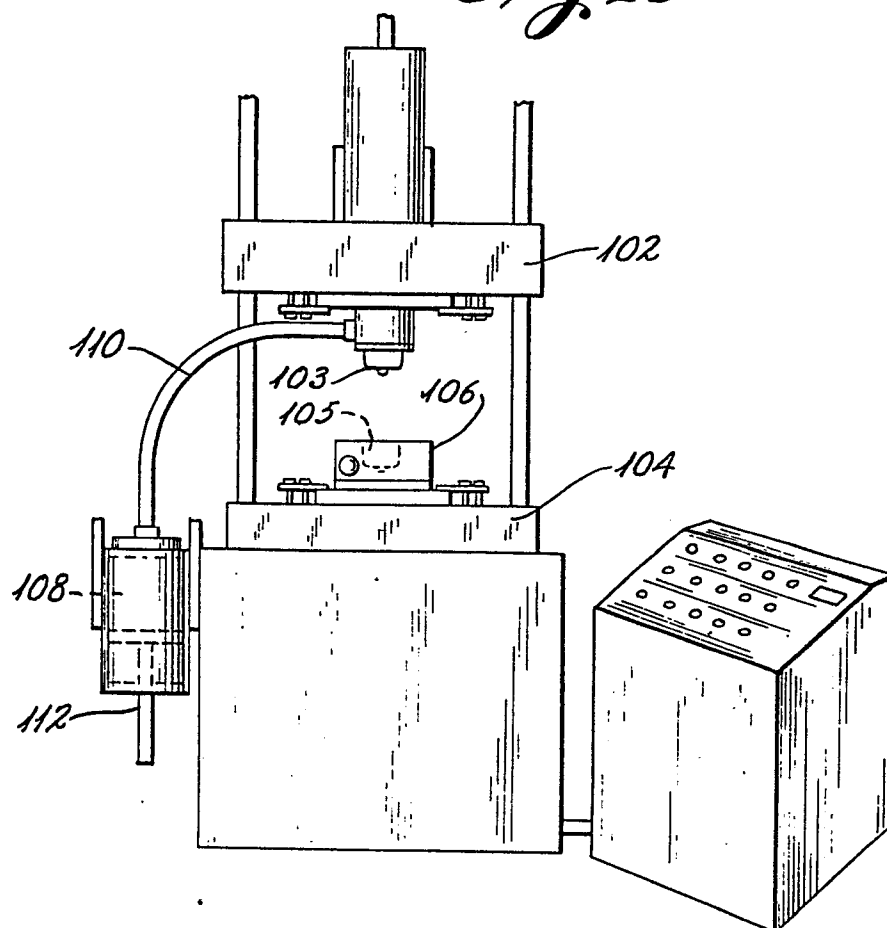
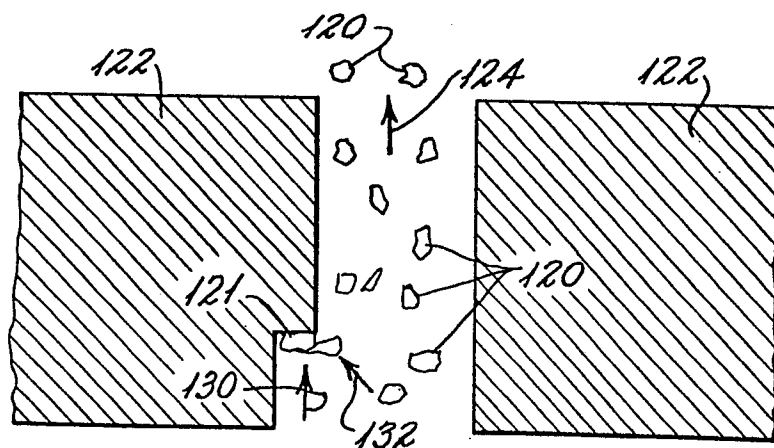
Fig. 18*Fig. 19*

Fig. 20

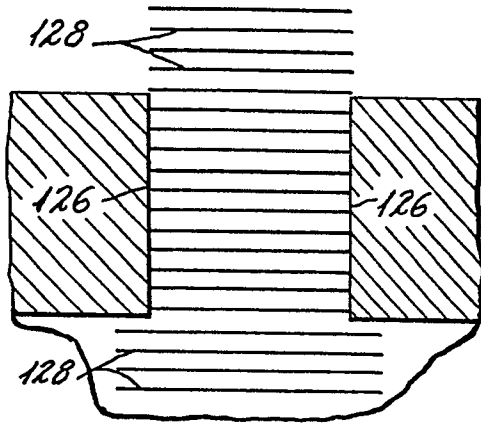


Fig. 21

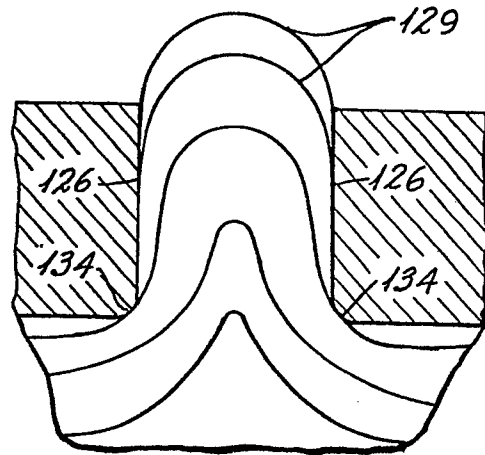


Fig. 22

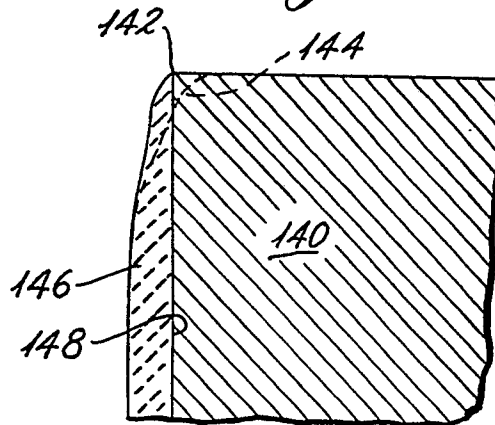


Fig. 23

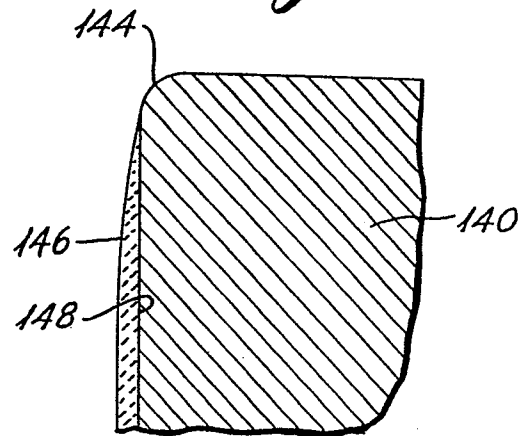


Fig. 24

