Nov. 9, 1965 R. D. HALVERSTADT ETAL 3,216,854

METHOD FOR MAKING AN ELECTROLYTIC GRINDING WHEEL

Original Filed June 6, 1960 5 Sheets-Sheet 1

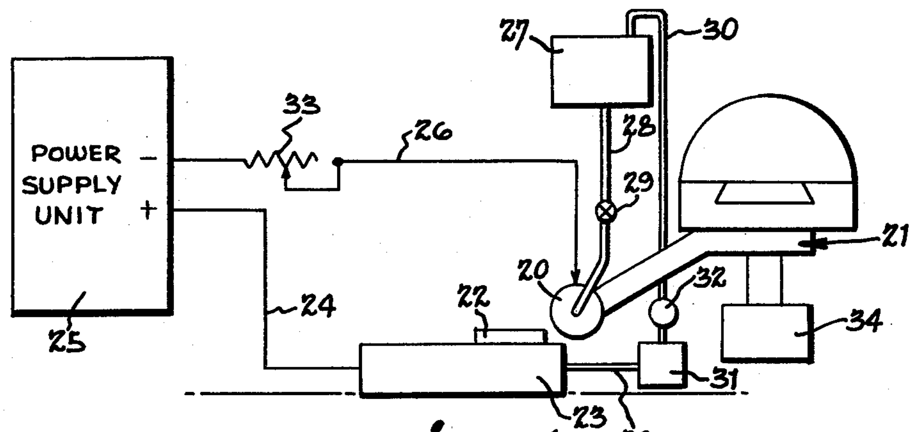

Fig. 1

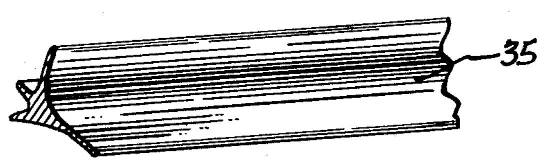

Fig. 2

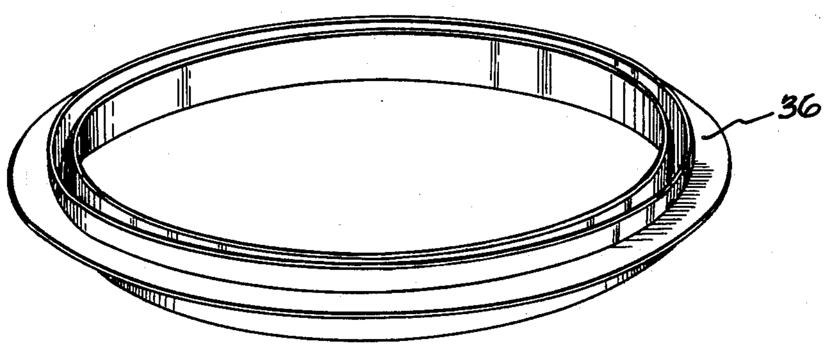

Fig. 3

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METHOD FOR MAKING AN ELECTROLYTIC GRINDING WHEEL

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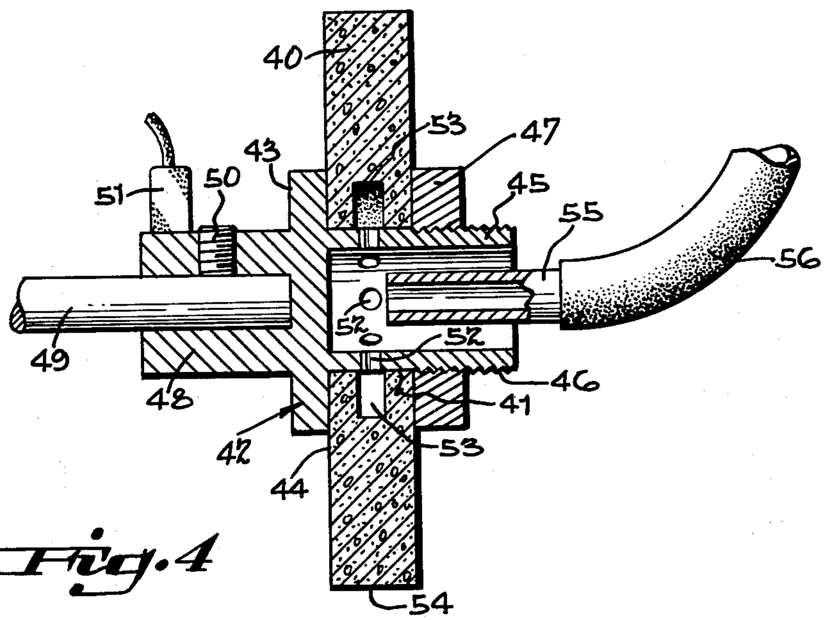
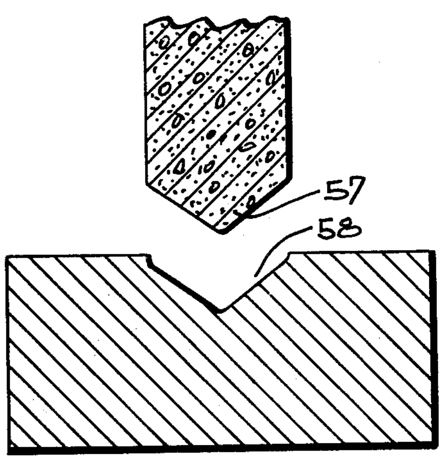


Fig. 4



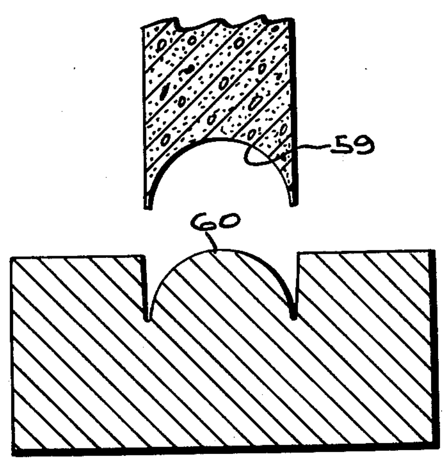


Fig. 5

Fig. 6

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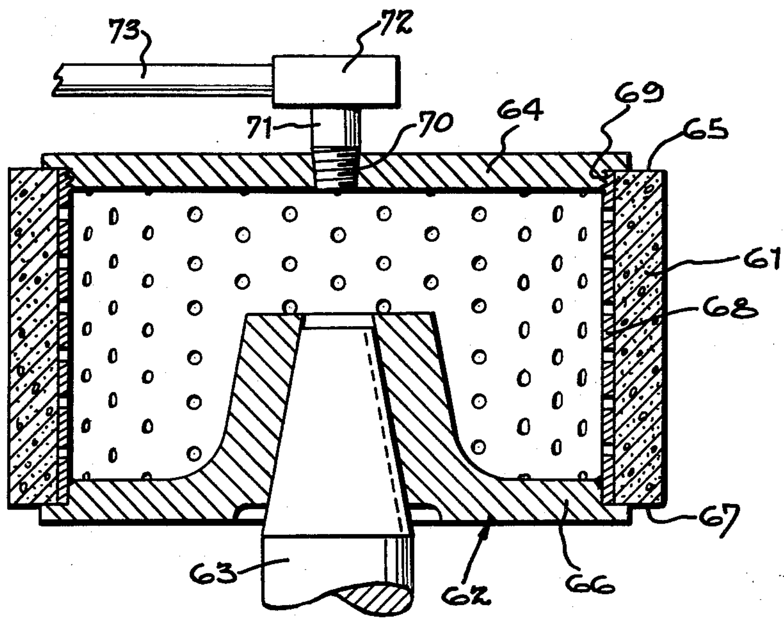

Fig. 7

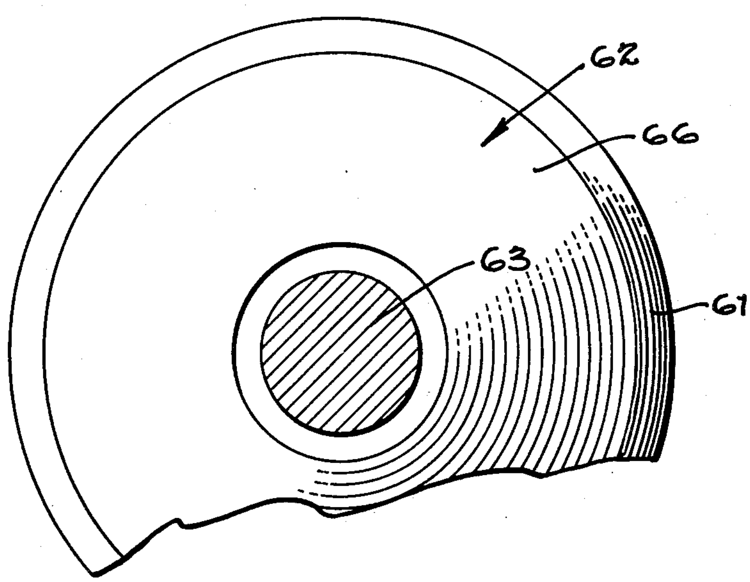

Fig. 8

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METHOD FOR MAKING AN ELECTROLYTIC GRINDING WHEEL

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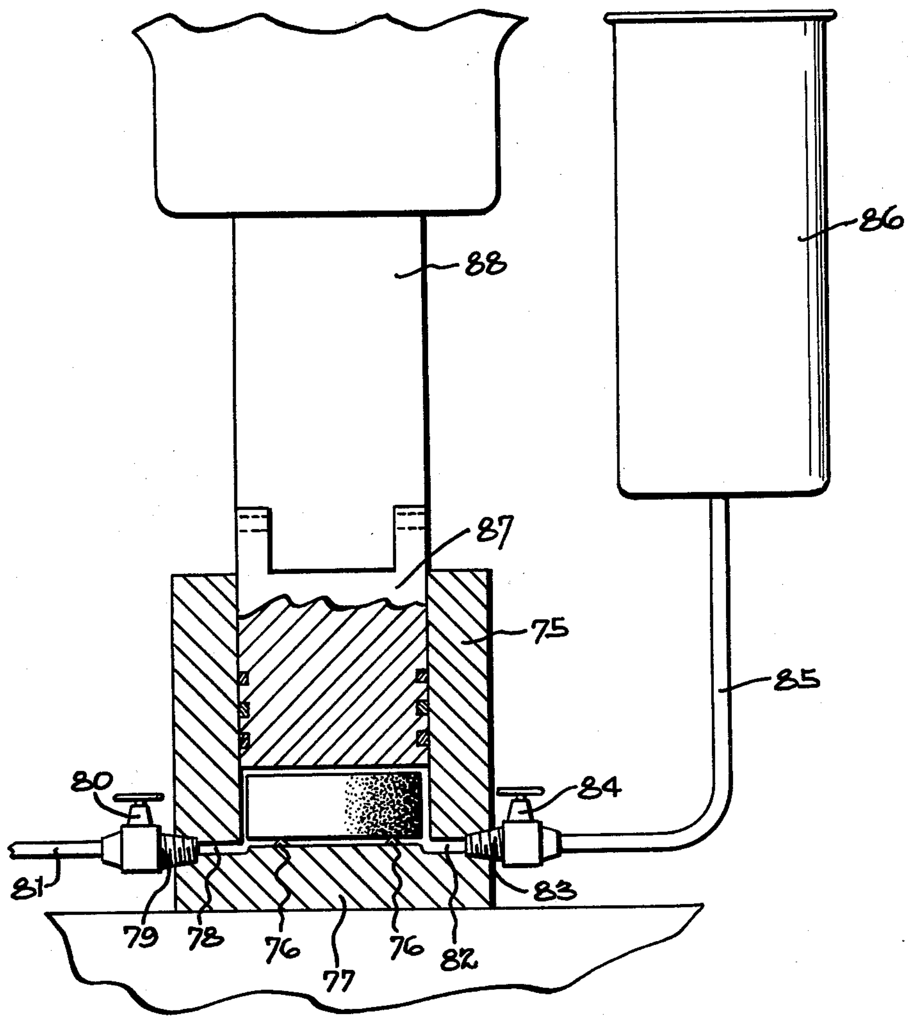

Fig. 9

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METHOD FOR MAKING AN ELECTROLYTIC GRINDING WHEEL

Original Filed June 6, 1960 5 Sheets-Sheet 5

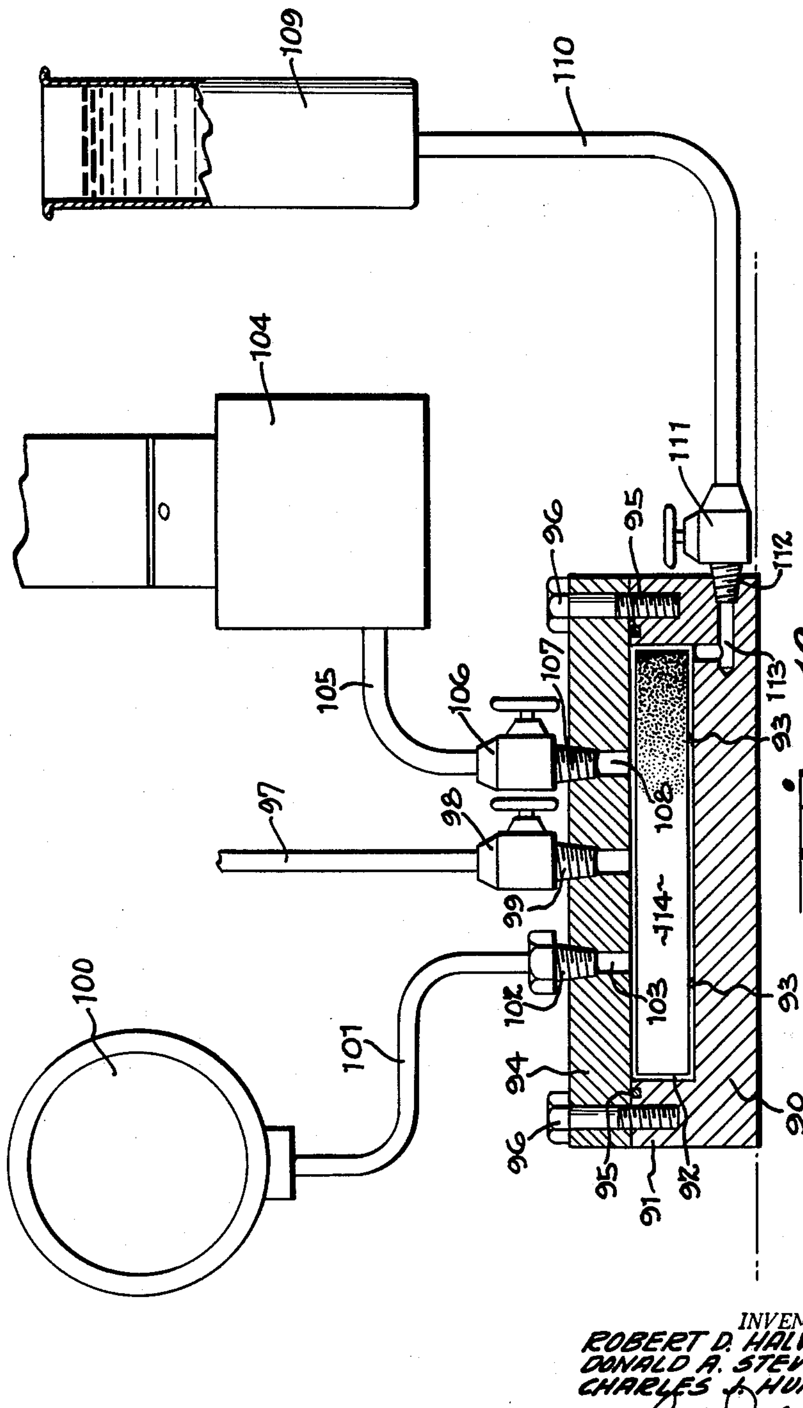

Fig. 10

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METHOD FOR MAKING AN ELECTROLYTIC GRINDING WHEEL

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Original application June 6, 1960, Ser. No. 34,334. Divided and this application Sept. 28, 1962, Ser. No. 240,776

2 Claims. (Cl. 117—213)

This is a divisional application of application S.N. 34,334, filed June 6, 1960 and assigned to the assignee of the present invention.

This invention relates to an improvement in the art of removing metal from a workpiece by electrolytic erosion. The common or shop term for two forms of this art is "electrolytic grinding" and "electrolytic drilling," regardless of the amount of actual mechanical grinding or drilling which takes place.

Until comparatively recent years, all metals, including commercially available alloys, could be formed and finished by conventional cutting tools and grinders. However, the development of high-performance power producing apparatus such as gas turbines brought about the invention and production of a class of metals which are commonly called super-alloys. The efficiency of gas turbines generally increases very substantially with the increase of the temperature of the gases produced by the combustion of the fuel. Hence, the development of this type of turbine required materials suitable for structural parts which would maintain adequate rigidity in the presence of heavy deforming stresses at temperatures such as 1500° F. and above. Further, for these turbines to have any substantial life, it was and is necessary that the critical structural parts be very hard and resistant to erosion and corrosion by the high velocity streams of hot gases. The so-called super-alloys, as materials, were the answer to the exacting requirements of the gas turbine engine. The solution of the problem of suitable materials, however, posed the new problem of their fabrication. The cathode made according to this invention was particularly developed to alleviate this problem.

The super-alloys are very resistant to all common metal shaping operations. On a practical production basis, complex articles made from these alloys cannot be machined by edge-cutting tools or by grinding. In the typical gas turbine, there is need for super-alloy parts of intricate and thin cross sections which must be held to close dimensional tolerances, such as one ten thousandth of an inch (.0001). The fabrication of parts of thin cross section from available super-alloy stock often requires removal of far more material than remains as the finished part.

At present, the super-alloy parts are fabricated from the super-alloy stock by conventional grinding with a vitrified aluminum oxide grinding wheel. In many cases, it is not feasible to remove more than one thousandth of an inch (.001) from the surface of the workpiece in a single pass. Many fabricating operations require the removal of metal from the workpiece to a depth of one-half inch or more. Hence, this fabrication with the conventional grinding wheel is highly time-consuming and tedious, to say the least. Further, this grinding tends to produce stresses and actual flaws at the surface of the workpiece which may become the foci of failure of the part. If, on inspection, a flaw appears in a part it must be rejected. This necessary precaution results in the production of a substantial quantity of very expensive scrap. Further, such conventional grinding often introduces a residual stress which is not visually apparent but which causes premature failure during operation.

To overcome the slow rate of grinding with vitrified aluminum oxide wheels, the use of diamond grinding wheels has been tried. For simple, uniform cutting, diamond wheels may be useful. However, diamond wheels have never proved feasible for pure abrasive grinding of anything but sintered carbide, ceramic and the like. They "load" too easily with softer materials. In addition, the cost of diamond wheels is many times greater than such wheels as vitrified aluminum oxide.

However, even if diamond wheels were feasible for pure abrasive grinding, they would have to be reconditioned after very limited usage because the hardness and toughness of the super-alloy is such that even a diamond grinding wheel has limited useful life. Reconditioning a metal bonded diamond wheel is virtually impossible where intricate shapes are required. Therefore, intricate electrolytic grinding using such wheels is virtually impossible.

One object of the present invention is to improve the art of shaping and finishing metal workpieces falling within the super-alloy category by providing a method and apparatus for making a special tool for this purpose which combines the electrical advantages of a metal electrode with the mechanical advantages of a dielectric material. Although the invention and its advantages are described and explained primarily in relation to the problems which were created by the introduction of the super-alloys, the cathodes made according to this invention may also be used for shaping or dressing metal bonded carbide cutting tools, metals too hard for conventional machining and grinding, and softer or ordinary metals, if expedient.

Another object is to provide a method and apparatus for making an improved cathode for rapid electrolytic and mechanical erosion of metal, which cathode combines low cost with good dressability, particularly in complicated intricate shapes.

Other features and objectives of the invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatic view of grinding apparatus utilizing a cathode made according to the invention;

FIG. 2 is a fragmentary view of an element shaped by grinding with a cathode made in accordance with the invention;

FIG. 3 is a perspective view of an element shaped by grinding with a cathode made in accordance with the invention;

FIG. 4 is a cross-sectional view of a grinding wheel made in accordance with the invention;

FIGS. 5 and 6 are diagrammatic cross-sectional views of grinding wheels and workpieces illustrating the operation of wheels made in accordance with the invention;

FIG. 7 is a cross-sectional view of an alternative type of grinding wheel;

FIG. 8 is an end elevational view of the grinding wheel of FIG. 7;

FIG. 9 is a diagrammatic view partly in section of apparatus for impregnating a grinding wheel; and

FIG. 10 is a diagrammatic view partly in section of alternate apparatus for impregnating a grinding wheel.

In one form, this invention provides a method and apparatus for making a cathode composed of material which is a non-conductor, or an inadequate conductor of electricity, but which is permeated by pores collectively constituting a continuous system. These pores are impregnated with a material which is or can be made to be a good conductor of electricity. This impregnation may be complete, with the pores fully filled, or partial, with the walls of the pores merely coated enough to provide a continuous electrical path through the material. In either case, the resulting cathode is characterized by mechanical properties which can only be found in dielectric materials and electrical conductivity akin to that of metals.

In another form this invention provides a vacuum then pressure impregnation method and apparatus for making the improved cathodes.

In electrolytic grinding and electrolytic drilling, a direct current is passed through an electrolyte disposed as a film between the workpiece and a complementary electrode which corresponds functionally with the cutting or abrading tool customarily used for removing metal from a workpiece. This electrode may or may not provide a mechanical removal of metal coincidentally with the electrolytic erosion, depending upon the composition of the electrode and the manner in which it is applied to the workpiece. Regardless of whether or not abrasive metal removal takes place, the rotating electrode "scrubs" the surface being cut and removes any passivating film left as a product of electrolysis.

Direct current, which is passed through this film of electrolyte from the anode workpiece to the cathode "tool," tends to remove metal from the anode and plate it on the cathode. The chemistry of the operation is no different from that of an ordinary electroplating process except that the electrolyte is constituted to precipitate the metal ion removed from the workpiece so that it will not be plated or deposited on the cathode. The principle of the process is sometimes referred to in the art as "deplating."

The cathode made according to this invention permits the use of high current densities in the film of electrolyte between the cathode and the workpiece and also permits supplementation of electrolytic erosion by the mechanical action of the cathode on the workpiece as a cutting or grinding medium as well as an improved scrubber. By appropriate selection of the material of the body of the porous cathode, the mechanical action may be varied from a light rubbing or polishing to substantial grinding or cutting. In any case, the cathode made according to this invention combines any desired physical properties of a nonmetal with the conductivity of a metal.

The electrolyte used in conjunction with the electrode made according to this invention may be applied by spout to the interface between the cathode and workpiece, but it is considered preferable to apply the electrolyte through the porous system of the cathode to assure an adequate supply of electrolyte in the zone of erosion. This feed of the electrolyte through the cathode may be accelerated by feeding the electrolyte to the cathode under pressure or by centrifugal force if a rotating wheel-cathode is used. If the flow of electrolyte through the cathode is inadequate, the supply of electrolyte may be supplemented by a spout discharge.

The preferred cathode made according to this invention is a vitrified aluminum oxide grit grinding wheel which may be of any standard configuration and which is at least partially impregnated with an "electrically conductive material" or "electrically conductive ink," of the type now employed in the fabrication of printed circuits. A preferred ink is one which suspends finely divided silver oxide in a suitable vehicle. After the wheel is impregnated, the silver oxide is reduced to metallic silver by heat treating at a temperature at which silver oxdie reduces. "Electrically conductive" refers to the condition of the material or ink when the cathode is ready for use. The coating of ink on the walls of the pores of the wheels provides a relatively low-resistance electric connection between the hub of the wheel and the circular margin of the wheel. The electrolyte may be delivered to the point of use through the wheels' continuous system of pores. Further, a vitrified aluminum oxide grinding wheel is itself an excellent grinding tool in abrasive capacity and wear resistance. While reference has been made to the preferred vitrified aluminum oxide grinding wheel, vitreous bonded carbide wheels such as of silicon

carbide impregnated with electrically conductive material will perform, in many situations, equally as well as the aluminum oxide wheel.

Vitrified aluminum oxide grinding wheels are in common use and relatively inexpensive. The shops which perform grinding operations are accustomed to their use and are familiar with the techniques of dressing them. The partial imgregnation with the conductive ink does not detract from the mechanical properties of these wheels but imparts to them an electrical conductivity which converts an excellent grinding wheel into an excellent cathode for electrolytic erosion. The combination of good abrasive properties and good electrical properties permits this bi-functional tool to be used to produce variable ratios of electrolytic action to grinding action, which extend over a substantial range.

The present invention and its advantages are explained herein primarily with a reference to the partially impregnated vitrified aluminum oxide grinding wheel which is the preferred embodiment made according to the invention. While this wheel, and others embodying its principle, may be used on any metal desired, the most important utility of the wheel is best explained by reference to its most exacting condition of use.

In general, the cathode made according to this invention makes available a production tool capable of shaping metal to the most complicated configurations at a production cost many times less than the cost of any other method and with and other cathode. It makes possible close tolerance form grinding heretofore unobtainable because of the difficulty, if not impossibility, of dressing metal bonded diamond wheels to complicated shapes.

A wheel formed in accordance with the invention is employed in the grinding of a workpiece by apparatus diagrammatically illustrated in FIG. 1. There a wheel **20** is mounted on any suitable operating mechanism **21.** The mechanism includes means for reciprocating the wheel **20** longitudinally and transversely with respect to a workpiece **22.** The mechanism also includes means for rotating the wheel **20** at rates of speed which may be varied as required by the conditions of the particular grinding operation being performed.

The workpiece **22** is mounted on a conductive fixture **23** which is connected by a conductor **24** as an anode to the positive side of a direct current power supply **25.** A conductor **26** connects the negative side of the power supply to the wheel **20** so that the wheel **20** will become a cathode in the electrolytic circuit.

A reservoir **27** of electrolyte is connected by a tube **28** to a cavity in the central portion of the wheel **20.** A valve **29** is provided in tube **28** to regulate the flow of electrolyte to the wheel **20.**

A suitable electrolyte catch basin (not shown) as associated with the fixture **23.** A return tube **30** is provided for conveying electrolyte through a filter **31** and pump **32** back to reservoir **27.**

It should be understood that the apparatus illustrated in FIG. 1 is merely by way of example. Any suitable structure for mounting the grinding wheel and workpiece and for supplying electrolyte to the wheel and current between the wheel and workpiece can be employed without departing from the spirit and scope of the present invention.

FIGS. 2 and 3 are illustrative of the type of cross sections which can be formed from cathodes made by the process of the present invention. A shaped member **35** in FIG. 2 was formed by the electrolytic grinding process described above from a solid bar of approximately 1¼ inch stock. The metal was a super-alloy designated as M–252, which is constituted, in percent by weight, as follows:

C	.1 to .2
Cr	18 to 20
Co	9 to 11

Mo	6 to 11
Ti	2.25 to 2.75
Al	.25 to 1.25
Ni	Balance

Similarly, a circular member **36** was formed from 1 inch stock. In both members **35** and **36** it is important to note the thin fin configurations can be formed within as close tolerances as 0.0001 inch through the cathode made according to the process of the present invention because little or no mechanical force is exerted.

FIG. 4 illustrates one form of a wheel constructed in accordance with the present invention. A wheel **40**, which can be a standard vitrified aluminum oxide grinding wheel impregnated with a conductive substance in the manner described below, has a central opening **41**. The wheel **40** may be provided with an annular recess **53** which is disposed adjacent the orifices **52** so as to form a pocket to receive a reservoir of electrolyte, the electrolyte flowing from the pocket **53** through the pores in the wheel **40** out to the periphery **54** of the wheel.

Because the pores in the wheel **40** will be located at random throughout the wheel, the electrolyte will tend to disperse uniformly throughout the cross section of the wheel. Thus, there will be uniform distribution of electrolyte along the abrading surface **54** which is in contact with the metal.

FIGS. 5 and 6 illustrate two possible configurations of the type of wheel illustrated in FIG. 4. In FIG. 5 the edge of the wheel is generally triangular in cross section as indicated at **57**. The removal of metal will leave a similar concave groove **58** which is of the same triangular section.

In FIG. 6 the edge of the wheel is of concave semicircular section as indicated at **59**. The workpiece subjected to the action of the wheel of FIG. 6 will be formed with a semicircular ridge **60**. Although the grinding surface of the various forms of the wheels shown herein are illustrated as simple shapes, it is to be understood that such surfaces can be dressed to any shape, simple or complex, to result in correspondingly shaped ground surfaces on a workpiece.

FIGS. 7 and 8 illustrate a different form of wheel from that illustrated in FIGS. 4, 5 and 6. In FIG. 7 the abrasive portion of the wheel is a comparatively thin walled cylinder **61**.

As indicated above, an important aspect of the present invention is the provision of means for changing a normally non-conductive wheel to a wheel of sufficient conductance to form a cathode in an electrolytic circuit. The wheel may be of standard manufacture and of the type which is naturally porous. The vitrified aluminum oxide grit wheel is ideally suited for this purpose. In one form, the method of rendering such a wheel conductive comprises initially impregnating the wheel with a material which is conductive or can be made conductive. Such material can be carried into the interstices of a cathode, such as a wheel, by a fluid such as a liquid or gas. The only limitation on the size of material used to impregnate the catthode is that it be small enough to penetrate the pores or openings in the cathode and not be "filtered out." Thereafter the wheel is heated to drive off or decompose the fluid carrier, such as a solvent, and, when appropriate such as with the use of a thermally reducible oxide as silver, to make the material conductive. After such heating, the walls of the pores are uniformly coated with a conductive substance. In another form for use with electrolyte fed externally, the method of rendering the cathode conductive can merely consist of impregnating the cathode with a conductive material without regard to the creation of electrolyte-carrying pores.

Many suitable impregnating materials are available. Although they are sometimes referred to herein as "electrically conductive materials" or "electrically conductive inks" it is to be understood that such reference is intended to include in its meaning those materials which are electrically conductive as well as those materials which can be made electrically conductive, for example such as through heating to volatilize or decompose a carrier or to reduce an oxide to its free metal.

One type is an ink made from silver pigment suspended in a suitable carrier. The preferred type is a "silver pigment ink" of the type sometimes employed in the manufacture of printed circuits because such inks impart better conductivity to the cathode than a pure silver ink. This ink comprises a suspension of finely divided silver oxide in a resin carrier. The silver oxide of this ink will reduce to metallic silver at about 800° F. Trichlorethylene can be used as a solvent to thin the ink to approximately the consistency of water, a condition which has been found to be useful in the impregnation process.

More specifically, a preferred method of impregnating a wheel comprises the steps of first evacuating a chamber in which the wheel is located and thereafter introducing the conductive ink under pressure into the chamber so that the ink will flow freely and uniformly throughout the previously evacuated pores of the wheel. One form of apparatus for performing this method is illustrated in FIG. 9.

A cylinder **75** forms a chamber in which a grinding wheel is mounted on suitable supports **76** at the closed bottom wall **77** of the cylinder. A vacuum passageway **78** is formed in the wall of the cylinder and is connected by a fitting **79** and valve **80** to a line **81** which is in turn connected to a vacuum pump not shown. A liquid passageway **82** is also formed in the wall of the cylinder **75** and connected by a fitting **83** and valve **84** to a line **85**. The line **85** is connected to a supply of conductive ink **86**. A piston **87** is reciprocably mounted in the cylinder **75** and is actuated by a hydraulic ram **88**.

The following is an example of a process for impregnating the wheels and is not to be considered to be a limitation on the scope of the invention. In the apparatus shown, a vitrified aluminum oxide wheel of 2" x 2" x 1" made from particles of 100 grit size or larger was placed in the chamber formed by the cylinder **75**. The chamber was evacuated to approximately 28.5 inches of mercury vacuum to remove as much air from the pores of the wheel as possible. An ink including silver oxide suspended in a liquid carrier was thereafter admitted to fill the chamber. The hydraulic ram was then operated to drive the piston downwardly to apply a pressure of 3,000 p.s.i. The thus impregnated wheel was removed from the apparatus and baked at a temperature, for example 800° F., to decompose and drive off the liquid carrier and to cause the impregnation to become conductive by reduction of the silver oxide to metallic silver. The treated specimens were found to be completely conductive. The method described above will be particularly applicable to small diameter wheels.

The apparatus of FIG. 10 is designed for the impregnation of larger diameter wheels. The apparatus comprises a plate **90** having an annular flange **91** projecting vertically to form a circular cavity **92**. The bottom wall of the cavity is provided with point supports **93** to receive the wheel to be impregnated. The cavity **92** is enclosed by a plate **94** and sealed and an O ring **95**, the plate **94** being clamped to the flange **91** by bolts **96**.

A vacuum pump not shown is connected by a line **97** through a valve **98** and fitting **99** to the cavity **92**, the fitting **99** being connected to a bore in the plate **94**. A pressure gauge **100** is also connected to the cavity **92** through a line **101** and fitting **102** threaded in a bore **103** in the plate **94**. The pressure gauge is adapted to indicate vacuum as well as pressure, for example, up to 3,000 p.s.i. A hydraulic press **104** adapted to deliver a pressure, for example, of 3,000 p.s.i., is connected through a line **105**, valve **106** and fitting **107** to the cavity **92**. The fitting **107** is connected to the cavity **102** through a bore **108** in the plate **94**. A conductive ink reservoir **109** under atmospheric pressure is connected through a line **110**, valve **111** and fitting **112** to the cavity **92**. The fitting **112** is connected to the cavity **92** through the passageway **113** formed in the plate **90**.

Again, by way of example, a grinding wheel indicated at **114** was rendered conductive by the following process. The grinding wheel **114** was positioned on the supports **93** in the cavity **92** and the plate **94** was applied by the bolts **96**. The cavity was first evacuated to approximately 28.5 inches of mercury vacuum to remove air from the pores of the wheel. Thereafter valve **111** was operated to admit silver ink under atmospheric pressure to fill the cavity **92**. The valve **111** was closed and valve **106** operated in conjunction with the hydraulic press **104** to place the cavity **92** under a pressure of 3,000 p.s.i. The applied pressure caused a thorough impregnation of the wheel with the silver ink. Thereafter, the wheel **114** was removed and baked at 800° F. to decompose and drive off the liquid carrier and to cause the impregnation to become conductive.

A particular advantage in using silver as an electrical carrier in the cathode of this invention is that any oxidation of the silver during operation can be removed by simply heating the cathode to reduce the oxide to metallic silver.

Although the present invention has been described in connection with specific examples, it will be understood by those skilled in the art the modifications and variations of which this invention is capable particularly in regard to the variety of types of conductive materials, electrolytes and cathodes which can be used.

What is claimed is:

1. A method of making an electrolytic grinding wheel from a grinding wheel composed of grit and a dielectric grit bonding medium permeated with pores comprising the steps of:

sealing the grinding wheel in a gas tight chamber;

evacuating air from the chamber and from the pores of the wheel;

with the chamber still evacuated, introducing into the chamber a liquid including a resin and a silver oxide pigment under pressure to fill the chamber;

applying to the liquid a pressure of at least approximately 2500 pounds per square inch until the liquid thoroughly and substantially uniformly impregnates the wheel; and then

heating the impregnated grinding wheel to drive off volatile constituents of the liquid and to reduce the silver oxide to metallic pigment to produce an electrically conductive film on the walls of the pores, thereby rendering the wheel electrically conductive.

2. A method of making an electrolytic grinding wheel from a grinding wheel composed of grit and a dielectric grit bonding medium permeated with pores comprising the steps of:

sealing the grinding wheel in a gas tight chamber;

evacuating air from the chamber and from the pores of the wheel;

with the chamber still evacuated, introducing into the chamber a liquid under pressure to fill the chamber, the liquid including a resin and a pigment selected from the group consisting of silver and silver oxide;

applying to the liquid a pressure of at least approximately 2500 pounds per square inch until the liquid thoroughly and substantially uniformly impregnates the wheel; and then

heating the impregnated grinding wheel to drive off volatile constituents of the liquid and to reduce any silver oxide to metallic pigment to produce an electrically conductive film on the walls of the pores, thereby rendering the wheel electrically conductive.

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