

[54] **METHOD FOR PLATING ARTICLES WITH PARTICLES IN A METAL MATRIX**

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204/224 M; 204/273; 204/DIG. 10

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[58] Field of Search 204/26, 16, 217, DIG. 10,
204/224 M, 273, 275

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[57]

ABSTRACT

The surface of a workpiece which is to be plated is immersed in a plating solution of particles dispersed in a metal salt dissolved in an aqueous solution. The plating solution flows between the surface and an abrasive tool which rubs against the surface. An electric current is passed from the tool through the plating solution into the workpiece thereby causing metal ions to plate out as metal onto the surface of the workpiece. The particles within the plating solution become entrapped in the plated out matrix material. The pressure of the abrasive tool against the surface is enough to remove surface roughness but not enough to remove all the metal that is being plated out so that the coating builds up on the surface with the particles entrapped therein. The particle size, the pressure of the tool against the workpiece and the dispersal of the particles in the plating solution are several of the parameters which are controlled to achieve a uniform, high volume percent of particles within the plated matrix material. In a preferred embodiment the abrasive tool is a honing tool which rotates and reciprocates relative to the surface of the workpiece being plated.

13 Claims, 4 Drawing Figures

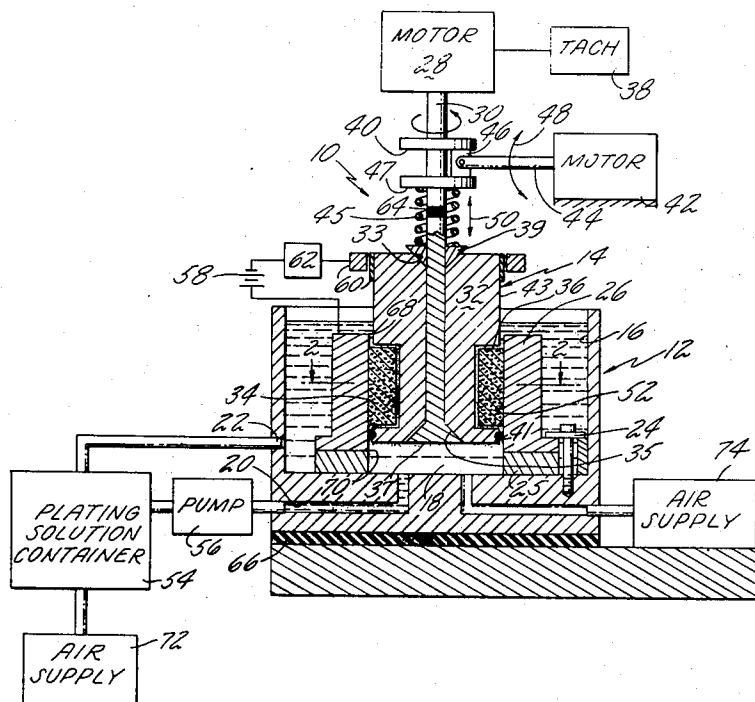


Fig. 1

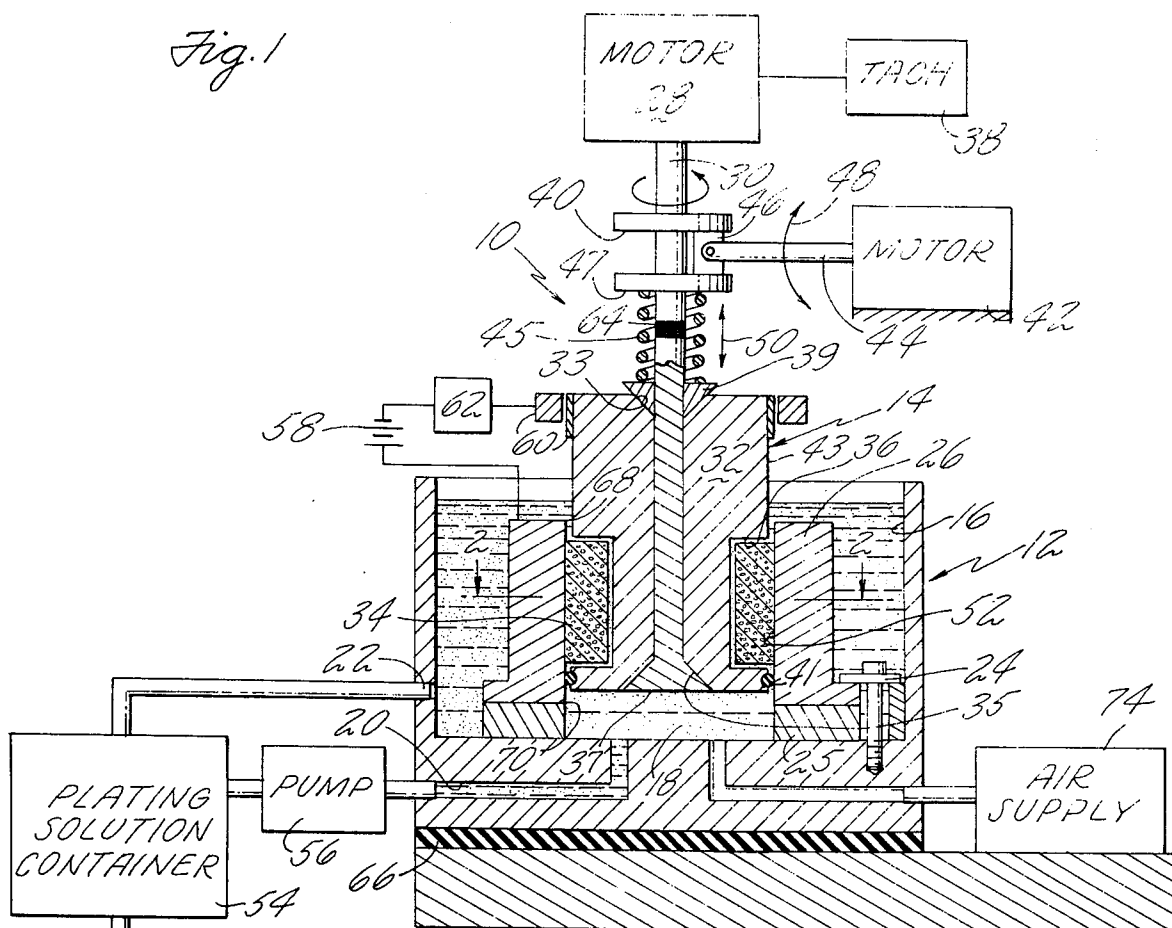


Fig. 2

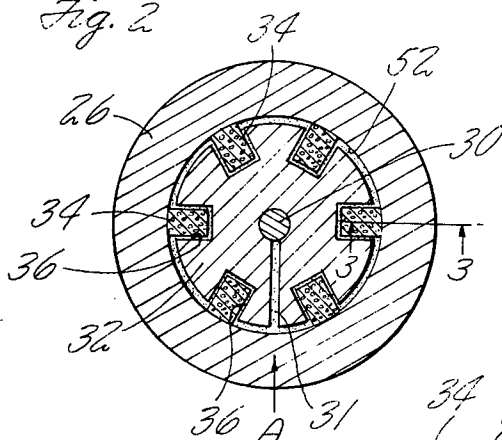


Fig. 4

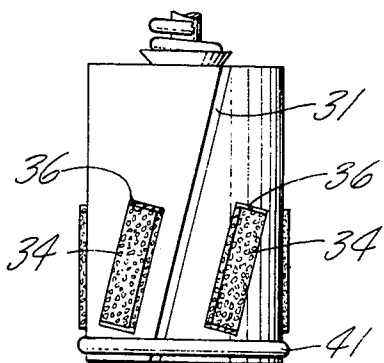
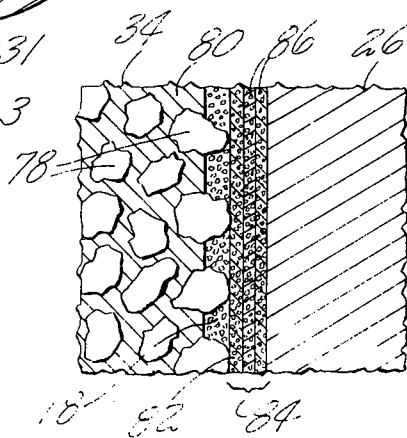


Fig. 3



METHOD FOR PLATING ARTICLES WITH PARTICLES IN A METAL MATRIX

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method of plating a metal surface, and more particularly to the plating of particles in a metal matrix.

2. Description of the Prior Art

Electroplating a metal coating onto a metal surface is well known in the art. For example, it is well known to mask off those areas of the workpiece where no plating is desired and to immerse the masked workpiece in a plating solution whereby an electric current is passed through the plating solution to the cathode workpiece and metal ions are attracted to the workpiece and metal is plated out on the surface of the workpiece. This is called tank or bath electroplating. An improvement over this technique, at least for some applications, is described in U.S. Pat. No. 3,616,289 to Ellis et al. wherein a honing operation is combined with a plating operation yielding good results with the ability to plate much faster than conventional tank plating methods and without the necessity for masking.

It is often desirable to apply a metal coating including particles distributed therein. These particles may impart various characteristics to the coating depending upon the material of the particles used. In particular, particles of very hard material may impart increased hardness to the coating or increase the tensile strength or modify other physical properties of the coating. The material in which the particles are embedded is generally referred to as the matrix material.

The aforementioned tank plating method has also been used for plating the surface of a workpiece with a metal matrix having particles dispersed therein; however, plating is slow and no more than about 25 volume percent particles can be plated. Furthermore, there is generally a nonuniform distribution of particles within the matrix material. By that it is meant that microscopic examination of the plated surface reveals heavy concentrations of particles in some areas and a sparse distribution of particles in other areas.

SUMMARY OF THE INVENTION

One object of the present invention is a method for applying a coating including particles in a metal matrix material to the surface of a workpiece wherein the particles are uniformly distributed throughout the matrix.

Another object of the present invention is a high speed method for coating the surface of a workpiece with a uniform distribution of and high concentration of particles in a metal matrix material.

Accordingly, a method for applying a coating of particles uniformly distributed in a metal matrix material to the surface of a workpiece includes flowing the plating solution between the workpiece and an abrasive tool which moves relative to the workpiece and presses thereagainst, passing an electric current from the tool through the plating solution and into the workpiece to cause metal ions to plate out metal onto the surface of the workpiece, while simultaneously entrapping particles within the metal plate, and controlling the particle size, the flow of the plating solution, the pressure of the tool against the workpiece and the dispersal of the particles in the plating solution to achieve satisfactory results.

In a preferred embodiment the abrasive tool is a honing tool. For example, the electroplate honing apparatus of the hereinabove mentioned Ellis et al patent may be used in the method of the subject invention. It has been found, however, that much more than the mere addition of particles to the plating solution used in the electroplate honing method of the Ellis et al patent is required to produce satisfactory results. Applicants' initial tests included merely adding particles to the plating solution and using the parameters which were known to produce satisfactory coatings by the electroplate honing method of Ellis et al. The results were totally unsatisfactory. Particles accumulated in clumps near the entrance to the workpiece and the volume percent of the particles over the surface of the workpiece was no greater than that achieved by simple tank plating.

After these initial attempts it was not understood what was causing the problems or what steps had to be taken to eliminate them. It was not even known whether there was any way of utilizing the broad concept of electroplate honing as disclosed in the Ellis et al. patent to achieve a satisfactory coating with a uniform dispersal of particles therein. Further experimentation gave insight into the problems associated with the electroplate honing method and the plating of particles such that a satisfactory method, which is the method of the present invention, was developed.

It was found, for example, that in order to achieve satisfactory results the pressure of the abrasive tool against the workpiece surface has to be carefully controlled. Too much pressure results in excessive dislodgement of the particles already embedded in the plated out matrix material by the action of the tool against the workpiece surface; this reduces the volume percent of particles in the final plate. It was also determined that excessive variations in the pressure during the plating operation are not tolerable since the pressure has an effect on the volume percent of particles in the plating. Therefore, variations in pressure during the plating operation may result in a nonuniform distribution of particles in the plating.

It was discovered that satisfactory results may not be achieved unless there is a uniform dispersal of the particles throughout that portion of the plating solution flowing between the abrasive tool and the workpiece surface. The flow rate of the plating solution affects this dispersal. Also, if the flow rate is too fast some of the particles may be washed away before they become securely embedded in the plated out matrix material; if the flow rate is too slow then the particles, particularly larger ones, might accumulate at low points due to gravity.

Additionally, it was found that the particle size is critical to the satisfactory operation of the method of the present invention. Large particles tend to accumulate at the entrance end of the workpiece in view of the close spacing between the workpiece and the tool.

By using the method of the subject invention, Applicants believe that a coating with a uniform distribution of particles in amounts up to 80 volume percent may be obtained.

The foregoing and other objects, features, and advantages of the present invention will become more apparent in the light of the following detailed description of preferred embodiments thereof as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an illustrative view, partly schematic, illustrating the apparatus used in the method of the subject invention.

FIG. 2 is a cross-sectional view taken along the line 2—2 of FIG. 1.

FIG. 3 is an enlarged, illustrative cross-sectional view taken along the line 3—3 in FIG. 2.

FIG. 4 is a view taken in the direction A of FIG. 2 with the workpiece 26 removed.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As an exemplary embodiment of the subject invention consider the hone-plating apparatus generally designated by the numeral 10. The apparatus 10 is illustrative only; the method of the subject invention may be practiced with a variety of apparatus, such as the apparatus of the heretofore mentioned Ellis et al. U.S. Pat. No. 3,616,289 which is incorporated herein by reference. Briefly, the apparatus 10 comprises a workholder 12 and a tool portion generally represented by the numeral 14. The workholder 12 includes a tank portion 16 for holding a circulating plating solution 18. The workholder 12 also has inlet and outlet passageways 20, 22, respectively, formed therein for introducing and removing the plating solution 18 from the tank portion 16. The workholder 12 also includes suitable workpiece fixturing means 24 for holding the workpiece (which is herein designated 26) securely in place within the tank portion 16 during the plating operation. The workpiece 26 is spaced from the bottom of the tank portion 16 by an annular spacer 25.

The tool portion 14 includes a motor 28, a shaft 30, a toolholder 32 and abrasive honing stones 34. The stones 34 are slidably mounted within slots 36 formed in toolholder 32 and can move radially outwardly with respect to the axis of the shaft 30. The shaft 30, toolholder 32 and stones 34 are rotated by the motor 28 which has a tachometer 38 associated therewith for indicating the speed of rotation. The speed of the motor may be varied as desired by suitable control means, not shown, in accordance with the method of the present invention as will hereinafter be explained in more detail. Means 37 are also provided to reciprocate the stones 34 parallel to the axis of the shaft 30. This means 37 includes an annular channel 40 around the shaft 30 and a reciprocating motor 42 including an arm 44 and slider 46. The slider 46 is positioned within the channel 40. The motor 42 moves the arm 44 back and forth, as indicated by the arrow 48, which in turn causes the shaft 30 to reciprocate back and forth in the direction of its axis, as indicated by the arrow 50.

In this example the workpiece 26 includes an internal cylindrical surface 52 which it is desired to plate with hard particles. The plating solution may comprise, for example, small particles of silicon nitride in an aqueous solution of nickel sulfate or nickel sulfonate. The composition of the particles and other details of the plating solution will be further discussed hereinafter, but in general the plating solution may comprise any metal salt dissolved in an aqueous solution. As shown in the embodiment of FIG. 1 the plating solution 18 is stored in a container 54 from which it is pumped by means of circulating pump 56 through passageway 20 into the tank portion 16, from whence it returns to the container 54 through passageway 22.

As shown in FIG. 1 the workpiece 26 is connected to a source 58 of direct current which is also connected, by brushes 60 or other suitable means to the toolholder 32 which is of conductive material. A control 62 is provided in the circuit for varying the power. During plating the workpiece 26 is maintained at a negative potential while the workholder 32 acts as an anode and is at positive potential. As best shown in FIGS. 1 and 2 the anode or workholder 32 is closely spaced from but is not in contact with the surface 52 of the workpiece 26. The stones 34 are non-conductive and electrical insulation is provided at 64 and 66.

In operation the toolholder 32 and the stones 34 reciprocate along the axis of the cylindrical surface 52 and rotate relative to the surface thereof. Positive metal ions in the plating solution 18 plate out on the negatively charged surface 52. As the metal matrix plates out the hard particles within the plating solution 18 become entrapped and embedded therein. Centrifugal force due to rotation of the toolholder 32 causes the abrasive honing stones 34 to press outwardly against the surface 52 as the matrix material is being plated out thereon. Thus, virtually simultaneously with the plating out of the matrix material, the stones 34 are removing the plated out matrix material. The amount of material removed by the stones 34 depends upon the pressure between the stones 34 and the surface 52, which is controlled directly by the rotational speed of the workholder 32. This rotational speed is maintained at a value whereby the rate of material removal by the stones 34 is slower than the rate of plating buildup.

In order to better understand the method of the present invention it is important to understand how the honing portion of the operation increases the plating rate. In the aforementioned prior art tank plating operation the plated out material does not build up smoothly on the surface of the workpiece; rather, the plated surface is quite rough and includes what is known in the art as "trees" or dendrites. The trees are like jagged hills of plate material. As these trees are formed during the plating process the surface area of the plated portion exposed to the liquid plating solution increases dramatically to as much as 5, 10 or 20 times the surface area of the workpiece without the trees. Since the current density is directly proportional to the plating rate and inversely proportional to the surface area exposed to the plating solution between the anode and the workpiece, the rate of plating a uniform thickness of metal is substantially reduced by the presence of the trees. In the method of the present invention the honing stones 34 continuously remove the trees as the plating is building up. Thus the current density and the rate of plating a uniform thickness of metal remains high at all locations and at all times.

The foregoing discussion relating to the removal of the trees by the honing operation is applicable whether or not particles are being plated. However, the trees create an additional problem when the material being plated includes particles in a metal matrix. The particles tend to accumulate around the trees rather than being uniformly dispersed within the plated out matrix material. The problem is not of significance with the method of the present invention since the trees are being continuously removed during the operation.

As hereinabove mentioned initial attempts to plate particles in a matrix material were unsuccessful. High concentrations of particles were found near the edges 68, 70 of the workpiece 26 while the distribution of

particles on the surface 52 between the edges was relatively sparse and unacceptable. One reason for this, we believe, is that the particles were not able to freely circulate between the toolholder 32 (anode) and the workpiece 26 (cathode) due to the very close gap therebetween. We found that using particles having a diameter no greater than 10 microns alleviated this problem. Preferably, the particle diameter should be less than 3 microns. The small particles not only flow more easily between the surface 52 and the workholder 32, but their uniform dispersion within the plating solution and between the workholder and the surface 52 is more easily maintained since larger particles tend to sink or accumulate at lower levels of the system due to gravity. In the embodiment of FIG. 1 means are provided to continuously agitate the plating solution to keep the particles uniformly dispersed and suspended throughout. For example, filtered compressed air supplies 72, 74 are associated with the container 54 and the tank portion 16 and continuously force bubbles of clean air into the plating solution causing vigorous agitation. If the particles are small enough the agitation caused by the circulating pump 56 may be sufficient in an of itself.

Referring now to FIG. 3, which is greatly enlarged for the purpose of illustration, the action of the honing stones 34 can be seen. Note that the honing stones 34 comprise abrasive particles 78 in a matrix material 80. The particles 78 of the honing stone 34 are shown rubbing against the outer most layer 82 of several layers 84 of already plated out matrix material with particles 86 embedded therein. The plating solution 18 with particles 86 in suspension is shown flowing between the honing stone 34 and the outer layer of plate 82.

It has also been found that the evenness or uniformness of the dispersal of particles within the plated out matrix material is affected by the rate of flow of plating solution between the surface 52 and the tool portion 14. The flow rate must be fast enough to cause sufficient agitation of the particles within the plating solution to keep them suspended therein and distributed uniformly throughout, but the flow rate should not be so fast as to wash away most of the particles in the plating solution before they have a chance to become entrapped and embedded in the matrix material as it is being plated out. It must be remembered that the particles are not primarily attracted to the surface 52 by the electrical charge, but rather are caught in the layers of matrix material as they are plated out during each back and forth stroke of the toolholder 32. The flow rate which gives the best results will vary depending upon the composition of the plating solution, the size of the particles within the plating solution and the amount of external agitation of the plating solution.

One technique which has been used successfully to assure this continuous flow of particles is to remove the pressure of the stones 34 against the surface 52 on alternate strokes of the toolholder 32. By doing this fresh plating solution is continuously being flushed between the parts. Another technique which is thought to be helpful and which is incorporated in the embodiment of FIG. 1 is the use of helical slots for the stones 34, as best shown in FIG. 4. The plating solution flows into the slots 36 around the stones 34; the helical shape of the slots create a pumping action as the toolholder 32 rotates.

Another factor which greatly affects the uniformity of the distribution of particles within the plated out ma-

trix material has been found to be the amount of pressure exerted by the stones 34 against the surface 52 of the workpiece 26 during the operation. As heretofore stated the pressure cannot be so great as to remove more material than is being plated. Generally, no more than a pressure of 2.0 psi should be used. More importantly, in order to maintain a uniform dispersal of particles within the matrix material, the pressure of the stones against the surface 52 should not be allowed to vary during any one stroke. The reason for this is that the plating solution is plated out in layers, a new layer being plated out on each forward and rearward pass of the stones 34 through the workpiece 26. The amount of pressure between the stones 34 and the surface 52 has a direct effect on the amount of particles which become embedded in each layer of the matrix material upon each pass. It is believed that as the honing stones 34 pass over the surface 52 they tend to dislodge, to a certain extent, particles which are already partially embedded in the plated out matrix material. Variations in the pressure of the stones against the surface 52 during a given stroke cause a variation in the amount of particles which are dislodged or scraped out of the plated matrix material along the axial length of the layer, thereby resulting in varying concentrations of particles within a layer. We have found that it is necessary to maintain the stone pressure constant to within ± 0.25 psi during a plating stroke to obtain satisfactory results.

In the plating field the objective is to obtain a uniform, defect free plating in as short a time as possible. As hereinabove mentioned, one factor affecting the plating rate is the current density at the surface 52. The current density is directly proportional to the spacing between the anode or toolholder 32 and the surface 52. In order to obtain maximum plating speed it is desirable that the gap between these two surfaces be 0.003 inch or less, and this gap should remain substantially constant as plating is building up. The smallness of this gap may have attributed to our early failures wherein the particles were accumulating at the edges 68, 70 of the workpiece, and may be part of the reason why particles of 10 microns in diameter or less are required to obtain satisfactory results. Obviously, large particles can cause blockage of flow between anode and cathode; small particles allow particle entrapment and total cover up of a given particle with matrix plate and subsequent removal of the surface "trees" down to a flat plane surface during a single plating pass.

As best shown in FIGS. 1, 2 and 4 the toolholder 32 is generally cylindrical in shape and is disposed around the shaft 30 and is keyed therewith so as to rotate with the shaft 30. The toolholder 32 is split along its axial length as at 31 and includes conical depressions 33, 35 at its upper and lower ends, respectively. The lower end 37 of the shaft 30 is formed as a frustum of a cone and the surface thereof mates with the surface of the conical depression 35 as shown in FIG. 1. A frusto conical wedge 39 is disposed on the shaft 30 and has its conical surface mating with the conical surface of the conical depression 33. The lower end of the toolholder 32 includes a rubber washer 41 which fits in an annular groove (not shown) in the toolholder 32. The washer 41 protrudes out from the external surface 43 of the toolholder 32 by an amount equivalent to the gap desired between the surface of the toolholder 32 and the surface of the workpiece 52. A spring 45 is disposed around the shaft 30 between the wedge 39 and the flat surface 47. The spring 45 exerts a force on the wedge

39 thereby tending to increase the outer diameter of the workholder 32 in view of the fact that the workholder 32 is split at 31. The spring constant of the spring 45 is selected so that enough pressure is exerted on the toolholder 32 to cause the washer 41 to continuously touch the surface 52 of the workpiece 26. In that manner a known gap is maintained between the toolholder 32 and the workpiece surface even as plating is building up on the surface of the workpiece. The foregoing is merely one technique for maintaining a predetermined gap between the toolholder 32 and the workpiece surface 52. Other techniques would be obvious to persons having ordinary skill in the art.

Further to obtaining a maximum plating rate, it is desirable that the volume percent of particles between the workholder 32 and the surface 52 and between the stones 34 and the surface 52 should be the same as the volume percent of particles elsewhere in the plating solution. Several of the steps already mentioned with regard to the method of the present invention are also useful for this purpose. For example, large particles are to be avoided since they are more affected by gravity and tend to settle out in the tank or to accumulate at low points in the system. Agitation of the plating solution is also very helpful; also, the flow rate of the plating solution through the system as controlled by the pump 56 will have an effect on the plating rate.

EXAMPLE 1

In this example the workpiece was made of iron. The plating solution comprised nickel dissolved in an aqueous solution of nickel sulfate including particles of silicon nitride (Si_3N_4). The particles comprised 50 volume percent of the total plating solution. The surface being plated was cylindrical and was 2.0 inches long and 2.0 inches in diameter. The rotational speed of the honing stones was 500 rpm. The toolholder was reciprocated at a rate of 1.0 cycle per second. The gap between the anode and the surface of the workpiece being plated was maintained at 0.003 inch. The pressure of the honing stones against the surface of the workpiece was maintained at 2.0 psi $\pm$ 0.25 psi during the entire plating operation. A current of 300 amps and a voltage of 6 volts was used. The temperature of the electrolyte was maintained at 120°F. The electrolyte was circulated at a rate of 10 gallons per minute. Using the foregoing parameters 0.001 inch of plate was satisfactorily deposited onto the surface of the workpiece per minute until a total plate thickness of 0.002 inch was obtained. The particle size within the plating solution was 1-3 microns. The finished plate included a uniform dispersal of 46 volume percent particles. The coating was tested to determine its quality. It had a low cycle fatigue life exceeding normal nickel plate and was securely attached to the surface of the workpiece.

EXAMPLE 2

In this example the workpiece was made of stainless steel. The plating solution comprised nickel dissolved in an aqueous solution of nickel sulfate including particles of tungsten carbide (W_2C). The particles comprised 60 volume percent of the total plating solution. The surface being plated was cylindrical and was 0.25 inches long and 0.375 inches in diameter. The rotational speed of the honing stones was 500 rpm. The toolholder was reciprocated at a rate of 1.0 cycle per second. The gap between the anode and the surface of the workpiece being plated was maintained at 0.002

inch. The pressure of the honing stones against the surface of the workpiece was maintained at 2.0 psi $\pm$ 0.25 psi during the entire plating operation. A current of 10 amps and a voltage of 6 volts was used. The temperature of the electrolyte was maintained at 120°F. The electrolyte was circulated at a rate of 10 gallons per minute. Using the foregoing parameters 0.001 inch of plate was satisfactorily deposited onto the surface of the workpiece per minute until a total plate thickness of 0.002 inch was obtained. The particle size within the plating solution was 3-5 microns. The finished plate included a uniform dispersal of 48 volume percent particles. The coating was tested to determine its quality. It had a low cycle fatigue life of 110 percent normal nickel plate and was securely attached to the surface of the workpiece.

Some other possible combinations of plating materials are, for example, aluminum oxide particles in an aqueous solution of chromium, or molybdenum disulfide particles in an aqueous solution of nickel. Also, titanium carbide particles in a nickel-cobalt aqueous solution may be used. Other desirable combinations will be obvious to persons having ordinary skill in the art.

Although in the foregoing examples Applicants achieved a particle density distribution of only about 50 percent, theoretically a particle density distribution of up to 80 percent should be possible with more sophisticated apparatus as opposed to the crude test equipment used by the Applicants.

Also, although in the preferred embodiment and in the foregoing examples honing stones are used, other abrasive surfaces may also be used. For example, the abrasive surface may be an endless belt backed with a conductive material which acts as the anode. Also, a simple grinding wheel could be used, as well as other abrasive media. These are all contemplated as being within the scope of the method of the present invention.

Furthermore, although the invention has been shown and described with respect to a preferred embodiment thereof, it should be understood by those skilled in the art that other various changes and omissions in the form and detail thereof may be made therein without departing from the spirit and the scope of the invention.

Having thus described a typical embodiment of our invention, that which we claim as new and desire to secure by Letters Patent of the United States is:

1. A method for applying a coating to the surface of a workpiece using a tool having an anode portion and a nonconductive abrasive surface portion, the coating including a substantially uniform distribution of particles in a metal matrix material including the steps of:
 - moving said abrasive surface portion relative to said workpiece surface;
 - maintaining said anode portion in closely spaced relationship to said workpiece surface;
 - flowing a plating solution of a metal salt dissolved in an aqueous solution between said workpiece surface and said abrasive surface portion and between said workpiece surface and said anode portion, said plating solution including said particles;
 - passing a direct electric current from said anode portion through said plating solution to said workpiece surface so that said workpiece surface is at negative potential;
 - maintaining a substantially uniform dispersal of said particles throughout that portion of the plating so-

lution flow between said abrasive surface portion and anode portion and said workpiece surface; and pressing said abrasive surface portion against said workpiece surface for at least a portion of the time that they move relative to each other with sufficient pressure to cause some of said particles which are suspended in said solution between said surfaces to become embedded in the matrix material as it is plated out, and to cause removal of roughness of any already plated matrix material without causing excessive dislodgement of particles embedded in the plated matrix material.

2. The method for applying a coating according to claim 1 wherein said particles in said plating solution are 10 microns in diameter or less.

3. The method for applying a coating according to claim 1 wherein said step of pressing includes applying a pressure of 2.0 psi or less and maintaining said pressure constant to within ± 0.25 psi.

4. The method for applying a coating according to claim 3 wherein said step of maintaining a substantially uniform dispersal of said particles includes maintaining the volume percent of said particles in that portion of the plating solution flowing between said abrasive surface portion and said workpiece surface and said anode portion and said workpiece surface substantially the same as the overall volume percent of said particles elsewhere in the plating solution.

5. The method for applying a coating according to claim 1 wherein said particles in said plating solution are 3 microns in diameter or less.

6. The method for applying a coating according to claim 4 wherein said particles are no greater than 10 microns in diameter and the step of maintaining the volume percent of said particles in that portion of the plating solution flowing between said anode portion and said workpiece surface and said abrasive surface portion and said workpiece surface substantially the same as the overall volume percent of said particles elsewhere in the plating solution includes controlling the flow rate of the plating solution between said abrasive surface portion and said workpiece surface and said anode portion and said workpiece surface to cause sufficient agitation of the particles within the plating solution to keep them suspended therein and distributed uniformly, said flow rate being slow enough to minimize washing away of the particles before they become securely embedded in the plated out matrix material.

7. The method for applying a coating according to claim 6 wherein the step of maintaining said anode portion in closely spaced relationship to said workpiece surface includes maintaining the distance therebetween substantially constant at 0.003 inch or less.

8. A method for applying a coating to the surface of a workpiece using a honing tool having an anode portion and a nonconductive abrasive surface portion, said abrasive surface portion being radially outwardly adjustable, the coating including a substantially uniform distribution of particles in a metal matrix material including the steps of:

rotating and reciprocating said workpiece surface and said abrasive surface portion relative to each other;

maintaining said anode portion in closely spaced relationship to said workpiece surface;

flowing a plating solution of a metal salt dissolved in an aqueous solution between said workpiece sur-

face and said abrasive surface portion and between said workpiece surface and said anode portion, said plating solution including said particles, said particles being no greater than 10 microns in diameter; passing a direct electric current from said anode portion through said plating solution to said workpiece surface so that said workpiece surface is at a negative potential;

maintaining a substantially uniform dispersal of particles throughout that portion of the plating solution flowing between said abrasive surface portion and said workpiece surface, and between said anode portion and said workpiece surface; and

pressing said abrasive surface portion against said workpiece surface during at least a portion of a reciprocating cycle with a pressure no greater than 2.0 psi to cause removal of roughness of any already plated matrix material without causing excessive dislodgement of particles embedded in the plated matrix material, and maintaining said pressure constant during said portion of said reciprocating cycle to within ± 0.25 psi.

9. The method for applying a coating according to claim 8 wherein the step of maintaining said anode portion in closely spaced relationship to said workpiece surface includes maintaining the distance substantially constant therebetween at no more than 0.003 inch to maximize plating rate.

10. The method for applying a coating according to claim 8 wherein said step of maintaining a substantially uniform dispersal of said particles includes alternating said pressing step with a flushing step wherein said abrasive surface portion is moved away from said workpiece surface for a short time.

11. The method for applying a coating according to claim 8 wherein said step of maintaining a substantially uniform dispersal of said particles includes controlling the flow rate of the plating solution between said abrasive surface portion and said workpiece surface and between said anode portion and said workpiece surface said step of controlling including maintaining the flow rate of the plating solution between said abrasive surface portion and said workpiece surface and said anode portion and said workpiece surface fast enough to cause agitation of the particles within the plating solution to keep them suspended therein and distributed uniformly, and slow enough to minimize washing away of the particles before they become securely embedded in the plated out matrix material.

12. A method for applying a coating to the surface of a workpiece using a honing tool having an anode portion and a nonconductive abrasive surface portion, said abrasive surface portion and anode portion being radially outwardly adjustable, the coating including a substantially uniform distribution of particles in a metal matrix material including the steps of:

rotating and reciprocating said workpiece surface and said abrasive surface portion relative to each other;

maintaining said anode portion at a substantially constant distance of no more than 0.003 inch from said workpiece surface to maximize plating rate by radial adjustment of said honing tool;

flowing a plating solution of a metal salt dissolved in an aqueous solution between said workpiece surface and said abrasive surface portion and between said workpiece surface and said anode portion, said plating solution including said particles, said parti-

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cles being no greater than 10 microns in diameter, said step of flowing including maintaining the flow rate of the plating solution between said abrasive surface portion and said workpiece surface and between said anode portion and said workpiece surface fast enough to cause agitation of said particles within the plating solution to keep them suspended therein and distributed uniformly, and slow enough to minimize washing away of the particles before they become securely embedded in the plated out matrix material; passing a direct electric current from said anode portion through said plating solution to said workpiece surface so that said workpiece surface is at a negative potential; and

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pressing said abrasive surface portion against said workpiece surface during at least a portion of a reciprocating cycle with a pressure no greater than 2.0 psi to cause removal of roughness of any already plated matrix material without causing excessive dislodgement of particles embedded in the plated matrix material, and maintaining said pressure constant during said portion of said reciprocating cycle to within ± 0.25 psi.

13. The method for applying a coating according to claim 3 wherein said step of maintaining a substantially uniform dispersal of said particles includes agitating said plating solution.

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