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Leland

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[54] **PROGRAMMABLE PULSE ELECTROPLATING PROCESS**

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[51] **Int. Cl.** **C23b 3/06;** C23b 5/50; C23b 5/56

[58] **Field of Search** .... 204/25, 26, 36, 51, 218, 204/228, DIG. 8, DIG. 9, DIG. 10

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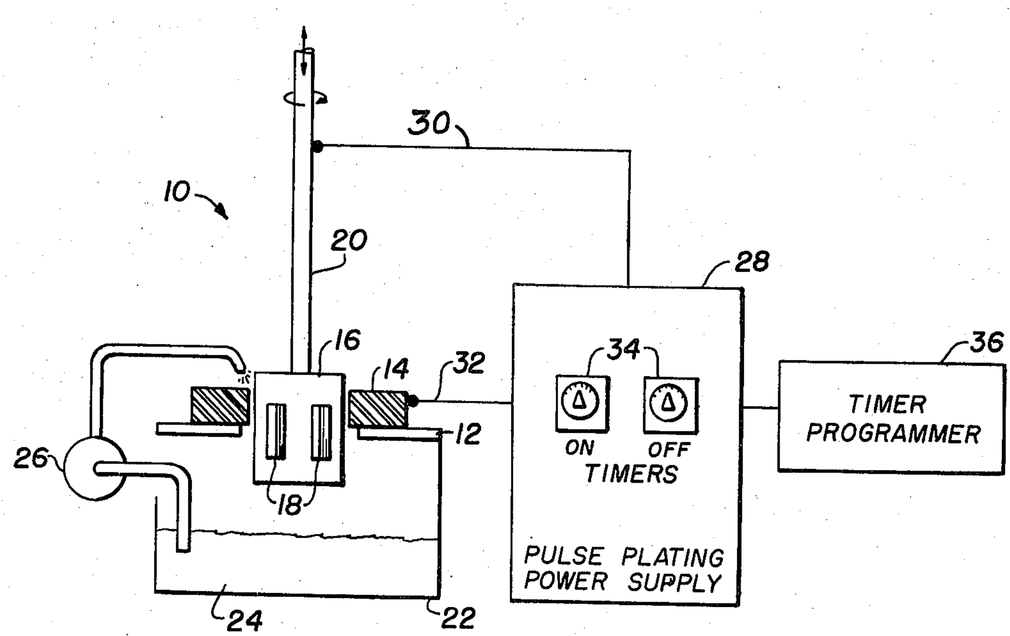
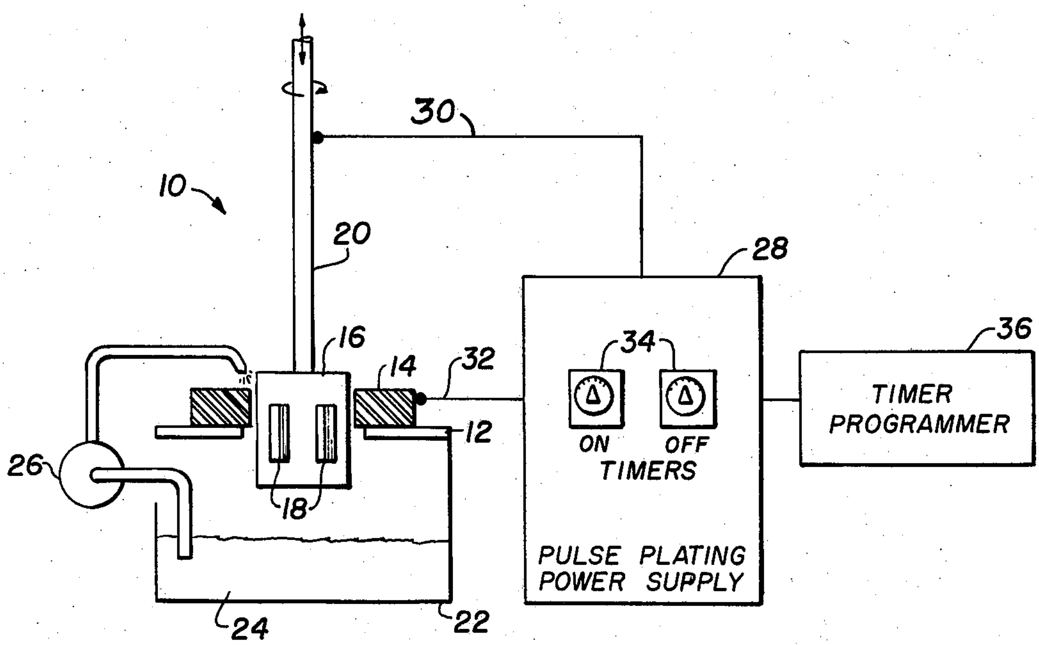
[57] **ABSTRACT**

An improved electroplating process is achieved by pulsing the current through an electrolyte containing a chromium plating solution generating hydrogen at the surface of a workpiece while simultaneously performing honing operation, to enable the hydrogen to escape intermittently during the reduced current periods to avoid the build-up of stress and to provide a softer plating coating adjacent to the workpiece, and, to thereafter, decrease the duration of the reduced current periods to retain the hydrogen and thus to increase the hardness of the outer layers of the plating where necessary to provide a heavy duty wearing surface.

5 Claims, 1 Drawing Figure




30
10
20
28
16
34
36
14
32
TIMER
PROGRAMMER
12
26
ON
OFF
TIMERS
18
PULSE PLATING
POWER SUPPLY
24
22

PROGRAMMABLE PULSE ELECTROPLATING PROCESS

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to a method and article of electroplating, designed primarily for electroplating hard metals such as chromium by means of a pulse-honing technique, but it is to be understood that the method can be used for any purposes for which it is found applicable.

The hone-forming process in the electroplating art is utilized in the industrial plating of cylinders, plates, and the like requiring a very hard outer work surface. This prior art process involves the simultaneous and combined operations of plating and machining, or mechanically working, the surface to be plated by a lapping or honing tool. The plating operation is conducted continuously with a steady DC current passing through a hard metal alloy electrolyte, such as chromium. The hone-forming process is described in U.S. Pat. Nos. 3,022,232; 3,183,176; and 3,637,469. The advantages of this type of plating process are several. Firstly, the build-up of the hard metal, usually chromium, is consistent throughout workpiece surfaces contacted by the hones filling in all the irregularities and providing a very smooth, accurate, and bright surface. Secondly, the process employs a high current density resulting in a high deposition rate, up to fifty times faster than the conventional electroplating tank process. The hone-forming process is also more expeditious, up to 3 mils thickness/minute, in that numerous rinsing and etching steps in the conventional plating process can be omitted. Consequently, the hone-forming process is more suitable to automatic production lines with a consequent savings of time and material. Thirdly, and most important is that the honing-plating technique produces an extremely hard surface achieved without special solutions or additions. Various tests have indicated that in hone-formed chromium plating a hardness of on the average of 1200–1400 Knoop can be obtained, as compared to 700–800 Knoop with conventional tank electroplated claddings. The higher hardness of the hone-forming process has been attributed to the mechanical work introduced in the plating process by the honing operation. It should be noted that in the hone-forming method the extreme hardness exists uniformly through the thickness of the plating.

The high degree of hardness offered by the hone-plating process has broad areas of applications, such as in original manufacturing of pumps, connecting rods, and especially in the reconditioning of worn surfaces in such components.

Although the combined hone-forming electroplating process offers numerous and significant advances, there is one serious and inherent disadvantage that naturally flows from this process. The high hardness existing throughout the thickness of the plated metal by the hone-forming process has locked-in residual tensile stresses adversely affecting the junction between the base metal and the plating causing adhesion failures. This can be primarily attributed to hydrogen embrittlement.

As will be described, the novel method of this invention solves the problem of excessive hardness, relieves the build-up of tensile stresses, and avoids hydrogen embrittlement. Thus, the invention process improves the hone-forming technique so as to have practical significance heretofore not achieved in the art.

SUMMARY OF THE INVENTION

It has been discovered that the adhesion problems in the high hardness plating obtained with the hone-forming technique can be greatly reduced by variably controlling the plating current, usually a DC source. This current control consists of providing "on" and "off" current periods by pulsing the plating current, instead of relying on the continuous steady current that is presently utilized in the hone-forming process. Of paramount importance in the invention process, is that the variable control of the current consists in varying the "off-time" current periods, and more specifically by decreasing the duration of the "off-time" periods to obtain a coating of graduated hardness.

It should be noted that the technique of uniformly fluctuating a plating current in the conventional electroplating of chromium on aluminum has been employed for many years in the ornamental plating art for plating household items such as tablewear, decorative bowls, etc. The purposes of this technique are to obtain a bright, decorative, corrosion resistant plating which is softer and thinner than decorative coatings obtained by the conventional tank plating methods. The softer and brighter chromium coating having a hardness approximately of **400** Knoop makes it more economical to polish by skilled workmen by the conventional buffing operation. In addition, the lesser hardness of the coating, produces a crack-free coating which is highly corrosive resistant. This enables a thinner coating to be utilized. It is obvious that these attributes materially reduce plating and buffing times, with a savings of plating materials, and contribute to a material savings in manufacturing cost of plating ornamental products.

However, the purpose in the invention method of pulsing the steady direct current in the hone-forming process, is to provide a soft bonding plating only at the junction of the plating with the workpiece to reduce the tensile stress that is inherently formed in the high hardness coatings obtainable in the hone-plating process. This is an important consideration since the current products plated with the hone-forming process inherently require in their use a very high hardness surface. Interrupting the plating currentt in the hone-forming process as proposed by the present invention provides deposition periods or "on time" and non-deposition or "off-time" periods. During the deposition period in chromium plating, it is important that only one layer maximum of the chromium hydride (CrH_x) is deposited on the base metal. During the subsequent non-deposition period, the CrH_x, being thermally unstable, is afforded time to decompose and the hydrogen gas is allowed to escape before the commencement of the next deposition period.

Thereafter, as the plating method progresses the pulsed power source is programmed so that the non-deposition, or "off-time," period is gradually reduced in duration to increase the hardness of the subsequent plating. It should be noted that during the programming of the "off-time" the "on-time" preferably remains constant. This gradual reduction of "off-time" continues until near the end of the process a zero "off-time" may be reached at which time the maximum hardness is obtained where needed at the wearing surface.

Thus, it is an important aspect of this invention to introduce in the hone-forming electroplating process a pulsing of the current, and equally important a pulsing at a variable rate to achieve a variable hardness without which the objects of this invention could not be achieved.

STATEMENT OF THE OBJECTS OF THE INVENTION

It is a principal purpose of this invention to provide a method for producing a hard metal alloy electroplating in which the tensile stresses and adhesion failures are minimized.

Another important object is to provide such a method for electroplating a hard metal alloy containing hydrogen which provides a plating having a minimum of hydrogen embrittlement.

Still another important object is to achieve the foregoing results by producing a hard metal alloy electroplating having a variable hardness in the plating thickness; and a corollary object is to provide such variable hardness gradient with the least hardness being at the juncture between the coating and the workpiece.

BRIEF DESCRIPTION OF DRAWINGS

The single FIGURE is a diagrammatic illustration of typical equipment which may be employed in the novel programmable pulse hone-forming method.

PREFERRED EMBODIMENT

Referring to the drawing, there is shown a diagrammatic view of the hone-forming equipment **10** that can be employed in practicising the novel method of this invention.

The hone-forming equipment may be of conventional, off-the-shelf design including a fixture **12** for supporting a workpiece **14**, such as a cylinder or the like have a core surface to be electroplated. A honing tool **16** having a plurality of circumferentially spaced honing stones **18** is adapted to be extended into the bore of the workpiece to mechanically work the surface simultaneously during the plating operation in a manner well known in the art as "hone-forming." Honing tool **16** is supported by a spindle **20**, which in the case of a cylindrical work surface is given a rotary and reciprocal motion in a manner illustrated in any of the aforementioned patents, and need not be illustrated. Although a cylindrical workpiece is illustrated in the preferred embodiment, it is understood that flat or other configured surfaces can be plated employing the invention process, and in such case the honing tool would have a conforming configuration.

Tank **22** contains a plating solution **24** which is circulated between the honing tool and the surface to be plated by a pump **26** and suitable piping. For hard metal industrial plating of bearing surfaces or the like, the electrolytic solution is usually a chromic acid.

An electric power supply **28** provides DC power for the electroplating operation. Power is connected to honing tool **16**, the anode, by conductor **30** through a suitable slip ring arrangement (not shown) and to workpiece **14**, the cathode, by conductor **32**. For purposes of this invention, as will be described later, power supply **28** must be a pulse-type rectifier having variable "on-time" controls and "off-time" controls. Such a pulse plating power supply is commercially available, from the Chem-O-Tronic Inc. of Justice, Ill. under "Chem-O-Plate" Model 1000.

The following description of the novel programmable pulse-honing process is applicable to any hard metal alloy plating electrolyte containing hydrogen ions, the most common electrolyte used for heavy industrial application being conventional chromium plating solution which will be used hereafter in the discussion as a typical plating solution.

The prior art hone-forming method of marrying the electroplating process and the hone-forming process is able to produce a substantially harder and heavier plating at a very high plating rate, and therefore offers many advantages in commercial production. However, as has been previously mentioned, the extreme hardness obtained by the hone-forming process inherently brings about a critical problem in that it causes a high residual tensile stress resulting in adhesion failures primarily due to hydrogen embrittlement. This characteristic is very detrimental in heavy commercial plating applications, such as cylinders and other bearing surfaces.

It is believed that this problem can best be appreciated by discussing the phenomena which occurs in the chromium deposition when applied to the hone-forming method. The chromium hydride (CrH_x) electrodeposited on the cathodic workpiece is thermally unstable and, upon deposition, commences to decompose and shrink into chromium metal and hydrogen atoms. Continuous deposition by the steady DC current employed in hone-forming, especially at the high deposition rate that is characteristic of this process, prevents the decomposition of the chromium hydride as the hydrogen ions have no opportunity to escape. This condition is believed to cause shrinkage crack patterns to occur in the deposited layers, the build-up of tensile stresses, and hydrogen embrittlement when occurring adjacent to the base metal being plated.

The present invention utilizes a pulsed current to provide alternate deposition, or "on-time", periods and non-deposition, or "off-time" periods, in contrast to the steady continuous current utilized in the conventional established hone-forming method. For reasons presently to be described, it is important in the present invention that the "on-time" plating periods be set so as not to exceed that time necessary to deposit one complete monolayer of CrH_x molecular units. And that the "off-time" periods be initially programmed to allow sufficient time for the CrH_x in contact with the plating solution to decompose, and the hydrogen atoms in the form of molecular gaseous hydrogen to escape before the next layer of CrH_x is deposited. In other words the previously deposited coating of CrH_x is allowed to decompose, or to partially decompose, before the next layer of CrH_x is deposited thereover. This technique will produce a softer plating.

It is important to note that decomposition of the CrH_x can not occur if the plating current is on continuously, as in the prior hone-forming method relying on a steady DC power, and thus the hydrogen gas is unable to escape and remains occluded in the coating to cause tensile stresses.

The optimum value of "on-time" period of the plating current, assuming a square pulse waveform, can be determined by the following equation:

$$t_{on} = \frac{Q}{(K_1)\,(CD)\,(CE)}$$

where:

Q = the quantity of CrH_x molecules required to cover one square inch of surface evenly and completely with one layer of CrH_x molecules = 1.2×10^{16} units/sq.in.

$$K_1 = \frac{1 \text{ unit}}{(6)\,(1.6 \times 10^{-19})} \text{ amp-sec (where Cr valence} = 6)$$

CD = Instantaneous true maximum current density in

$$\frac{\text{amps}}{\text{in}^2} \text{ (square wave assumed)}$$

CE = Current efficiency at the high current density (edge) area at the maximum instantaneous current peak (assumed to be 0.2 for this example)

Assuming maximum CD to be 5.0 amp/in^2, and solving for t_{on}

Maximum t_{on} = .0115 sec or 11.5 milliseconds

Having thus determined the duration of the maximum desired "on-time" periods for the plating current, the present invention proposes to vary the duration on the "off-time" periods to achieve the novel results. Accordingly, the hardness of the chromium deposits may be varied by controlling the length of the "off-time" periods, which in turn regulates the amount of hydrogen gas that is allowed to escape, between the limits of 100% hydrogen escape producing fully soft chromium, and 0% hydrogen escape producing fully hard chromium. The latter limit is always achieved with the conventional hone-forming method.

The length of the "off-time" periods can be controlled manually by timers **34** or automatically by timer programmer **36** both associated with power supply **28.** The programming of any specific plating operation will depend on many variables. Generally speaking, for industrial plating of heavy wearing surfaces the plating thickness may vary from 0.002 to 0.050 inch. Assuming a desired plating thickness of **0.020** inch, and a plating rate of one hour for each **0.010** inch plating thickness, and 50% "on-time" and "off-time" periods, which practically speaking may be considered suitable starting plating conditions, with an "on-time" of 11.5 milliseconds; the duration of the "off-time" period would be reduced for example by one millisecond approximately every 6 minutes during the process after an appropriate delay while forming the initial fully soft deposits. Before the final 0.003 to 0.008 inch plating thickness is reached, the "off-time" period is set to be zero or the desired minimum "off-time". Thereafter, the process usually amounts to a straight non-pulsed current with maximum hardness or the desired controlled hardness achieved at the outer plating surface.

An investigation of the honing process discloses that in a typical operation the vertical velocity of the honing tool is of a low order compared to a typical "off-time" pulse period, and, therefore, there is no need to coordinate the electrical pulses with respect to the mechanical position of the honing tool.

The novel invention method provides a significant and important improvement in the conventional hone-forming electroplating art giving practical utilization to its many advantages, especially in heavy plating applications. The build-up of stresses in the plating is avoided by allowing the hydrogen ions to escape during the plating process. This is accomplished by programming the plating current with "on-time" and "off-time" current pulses of predetermined durations. That is to say, that the chromium hydride that is deposited during an "on-time" current pulse is able to decompose or partially decompose in a controllable manner during the subsequent "off-time" current period, allowing the hydrogen to escape or to partially escape as desired before the next "on-time" plating current pulse. This results in an initial base plating of soft chromium that is not subjected to hydrogen embrittlement.

A significant step of the invention process is to gradually decrease the duration of the "off-time" pulses in order to gradually increase the hardness of the chromium plating, so that the outer workpiece surface will have the hardness that will satisfy the requirements in the particular application while avoiding hydrogen embrittlement of the base metal, and tensile-stress-adhesion failures of the plating.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. The method of controlling the plating hardness in a hone-forming process in which the surface of a metal workpiece is cathodically electroplated in an electrolytic chromium plating solution generating hydrogen at the workpiece surface, with a tool having a honing surface movable relative to and in engagement with the workpiece comprising the steps of:

applying a DC current through said electrolytic solution;

interrupting the flow of current through said solution to provide alternate deposition periods and non-deposition periods of predetermined duration;

gradually decreasing the duration of the non-deposition periods during the plating process;

whereby during the deposition period a layer of chromium is deposited on the work surface simultaneously with the honing operation, and during the non-deposition period a predetermined amount of the hydrogen is allowed to escape to control the hardness of the chromium applied to the surface of the workpiece and to reduce the stress between the plating and the workpiece, the hardness of the plating increasing as the duration of the non-deposition period decreases.

2. The method of claim **1** wherein the duration of the deposition periods is substantially constant throughout the plating process.

3. The method of claim **2** wherein the deposition period is not substantially longer than the time necessary to deposit one complete monolayer of the chromium.

4. The method of claim **1** wherein the non-deposition periods are gradually decreased to approach zero during the progression of the plating process to obtain the maximum hardness desired on the outer plating surface.

5. The method of claim **1** wherein the electroplating process utilizes only one plating bath.

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