

SPECIFICATION

TITLE OF THE INVENTION

Electrode for electric discharge surface treatment, method for
5 manufacturing the same, and method for storing the same

TECHNICAL FIELD

The present invention relates to a technology for electric
discharge surface treatment, and more particularly to a technology for
10 electric discharge surface treatment in which, by using a green compact
formed by compressionmolding a metallic powder, a metallic compound
powder, or a ceramic powder as an electrode, a pulse-like electric
discharge is caused between the electrode and a work, and with
discharge energy, a coat is formed on a surface of the work, the coat
15 being formed with an electrode material or a substance that is
generated by a reaction of the electrode material due to the electric
discharge energy.

BACKGROUND ART

20 A turbine blade of a gas turbine engine for aircrafts has to be
provided on its surface with a coat or hardfacing of a material having
strength and lubrication property in high-temperature environments. It
is known that Cr (chromium) and Mo (molybdenum) have a lubrication
property when oxidized in high-temperature environments. Therefore,
25 a Co (cobalt)-based material that contains Cr and Mo is used to form a

thick coat by a scheme, such as welding or thermal spraying.

The welding is a scheme using an electric discharge between a work and a welding rod to melt a material of the welding rod and adhere the material on the work. The thermal spraying is a scheme of spraying a metallic material in a melted state onto a work to form a coat.

However, the welding and the thermal spraying are both manual operations and require experience. Therefore, it is difficult to perform such operations on a production line, disadvantageously leading to an increase in cost. Moreover, since the welding in particular is a scheme in which heat intensively enters a work, when a thin material is processed or when a material that is easily broken, such as a single-crystal alloy or directionally-controlled alloy including a unidirectionally-solidified alloy, is processed, weld cracking is prone to occur, thereby disadvantageously reducing yield.

On the other hand, for example, a surface treatment technique through electric discharge machining (hereinafter, "electric discharge surface treatment") has also been established (for example, refer to patent literature 1).

Patent literature 1

International Publication No. 99/58744 Pamphlet

Patent literature 2

Japanese Patent No. 3227454

Patent literature 3

Japanese Patent Laid-Open Publication No. H5-148615

In forming a thick coat through this electric discharge surface treatment, the conditions having the most influence on coating performance are supply of an electrode material from an electrode, melting of the material supplied on a work surface, and bonding of the material with a work material. The strength, that is, hardness, of the electrode has an influence on supply of an electrode material. In the electrode manufacturing method disclosed in patent literature 1, with an electrode for electric discharge surface treatment being provided with hardness to some extent, the supply of an electrode material through electric discharge is suppressed, and the material supplied is sufficiently melted to form a hard ceramic coat on a work surface. However, the coat formed is limited to a thin film of which thickness is up to approximately 10 micrometers (μm).

Therefore, it has not been possible to form a dense and relatively thick coat (a thick film of the order of 100 μm or more) for purposes requiring strength and lubrication property in the high-temperature environments as described above.

Moreover, in the conventional electric discharge surface treatment, a green compact that is formed by compression molding a ceramic powder is used to form a coat of a hard material, such as TiC (titanium carbide), to improve abrasion resistance of a component and a mold. Such electrode used in the electric discharge surface treatment is manufactured by compression molding a ceramic powder with a press, and then by heating a resultant material (for example, refer to the patent literature 2).

In recent years, demands for forming a metallic coat having a lubrication property and corrosion resistance by the electric discharge surface treatment are increasing. It has become apparent by experiments performed by the inventors that, to form a metallic coat
5 having the lubrication property and the corrosion resistance by the electric discharge surface treatment, it is required to use a metallic powder having an average grain diameter of 3 μm or less to manufacture an electrode.

However, such metallic powder having an average grain
10 diameter of 3 μm or less tends to be coagulated into large solids due to a strong force occurring between grains by an action of an intermolecular force or an electrostatic force. If a green compact having such large solids is used for the electric discharge surface treatment, the large solids are deposited on the work surface, thereby
15 disadvantageously causing not only a short circuit and instability in the electric discharge but also deterioration in surface roughness of the coat.

In the invention disclosed in patent literature 2, a ceramic powder of which the force between grains is weak is used. Therefore,
20 powder is less prone to be coagulated into large solids even after being mixed with paraffin. Therefore, in the invention disclosed in patent literature 2, no measure is taken for addressing the coagulation of a metallic powder.

Furthermore, in a conventional metallic electrode manufacturing,
25 another electrode manufacturing technique different from a technique

using a green compact has been established, in which a metallic powder is molded with a press, and is then heated until the metal is completely melted. However, also in this case, since the metal is melted, no measure is taken for addressing the coagulation of a metallic powder.

Furthermore, in other conventional electrode manufacturing methods, a commercially-available ceramic powder is compression molded as it is with a press in an atmosphere, and is then heated to produce an electrode (for example, refer to patent literature 2).
10 Ceramics, which is used for such electrode, has a high oxidation temperature. Therefore, even when a dried powder having an average grain diameter of the order of 1 μm is left in an atmosphere, oxidation does not proceed. Thus, a ceramic powder having an average grain diameter of several μm is commercially available, and molding is easily
15 performed.

In addition, electric discharge surface treatment has been disclosed in which WC (tungsten carbide) and Co (cobalt) each having an average grain diameter of the order of 1 μm are used to form a thick coat layer having a coat thickness of several tens of millimeters (mm)
20 (for example, refer to patent literature 3). TiC, WC and Co are metals less likely to be oxidized. Other than Co, metals less likely to be oxidized include Ni (nickel). As such, a technique of forming a hard ceramic coat on a work surface using an electrode including WC or the like has been achieved by a conventional technology.

25 As described above, in recent years, there are increasing

demands a metallic coat having a lubrication property and corrosion resistance in high-temperature environments that is formed by, for example, electric discharge surface treatment. Also, for maintenance and dimensional correction of metal components, application of a thick
5 coat of metal or an alloy formed by the electric discharge surface treatment has been demanded. Furthermore, as described above, it has become apparent by the inventors that, to form a coat of metal or an alloy by electric discharge surface treatment, it is required to use a powder having an average grain diameter of 3 μm or less to
10 manufacture an electrode.

However, a metallic or alloy powder having a grain diameter of 3 μm or less that is available on the market is limited to powders of materials less likely to be oxidized. Thus, it is difficult to obtain powders of various materials for forming an electrode for electric
15 discharge surface treatment.

For example, Ti, which is light in weight, high in strength, and less likely to be oxidized at high temperature, is used for a compressor of a jet engine or the like. A solid solution (solid) of Ti is merely only slightly on its surface in an atmosphere, and its inside remains as Ti.
20 However, if Ti is powdered into a powder of which a grain diameter is several μm , an influence of a surface area with respect to a volume increases, and heat generated due to oxidation on a surface of the powder propagates inside grains, thereby causing oxidization also inside the grains. When oxidized, the powder loses its conductivity and
25 therefore cannot be used for an electrode for electric discharge surface

treatment. This is because the electrode cannot discharge electricity when the electrode cannot be energized. Moreover, oxidation of the Ti powder may explosively proceed. For the above reasons, it is difficult to obtain the powder having an average grain diameter suitable for manufacturing an electrode for electric discharge surface treatment, and even if the powder is available, the powder cannot be used for manufacturing an electrode for electric discharge surface treatment by the conventional methods.

In view of the above problems, it is an object of the present invention to establish technique of electric discharge surface treatment with which stable formation of a coat is possible.

In other words, it is an object of the present invention to obtain an electrode for electric discharge surface treatment with which formation of a dense thick coat is possible, a method for manufacturing such an electrode, and a method for storing such an electrode for electric discharge surface treatment.

Moreover it is an object of the present invention is to obtain an electrode for electric discharge surface treatment with which formation of a thick coat is possible by stable electric discharge without deteriorating surface roughness in electric discharge surface treatment using a metallic powder as a green compact electrode, and a method for manufacturing such an electrode.

Furthermore, it is an object of the present invention is to obtain a method for manufacturing an electrode for electric discharge surface treatment with which an electrode for electric discharge surface

treatment is easily manufactured even with a metallic powder likely to be oxidized or an alloy powder including metal likely to be oxidized to form a metallic coat in electric discharge surface treatment, and to obtain such an electrode for electric discharge surface treatment
5 manufactured by the method.

DISCLOSURE OF THE INVENTION

An electrode for electric discharge surface treatment according to the present invention is used in an electric discharge surface
10 treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a conductive ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work,
15 the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the discharge energy on the pulse. A powder solid formed through coagulation of the metallic powder, the metal compound powder, or the conductive ceramic powder included in the green compact has a size smaller than a distance
20 between the electrode and the work.

An electrode for electric discharge surface treatment according to the present invention is used in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a
25 pulse-like electric discharge is caused to take place between the

electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the discharge energy on the pulse. The
5 electrode is formed by finely crushing the metallic powder or the metal compound powder in a liquid that volatilizes in air, and includes compression molding the powder in a state of being not completely dried.

An electrode for electric discharge surface treatment according
10 to the present invention is used in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge
15 energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. The electrode is formed by compression molding the metallic powder or the metal compound powder finely crushed in a liquid that volatilizes in air
20 while being dried as pressured.

An electrode for electric discharge surface treatment according to the present invention is used in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a
25 pulse-like electric discharge is caused to take place between the

electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. The
5 electrode is formed by compression molding the metallic powder or the metal compound powder that is dried, after being finely crushed in a liquid, with an amount of oxygen in a dry atmosphere being adjusted, and is then oxidized only on a surface.

An electrode for electric discharge surface treatment according
10 to the present invention is used in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge
15 energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. The electrode is formed by compression molding the metallic powder or the metal compound powder having been finely crushed in wax.

20 An electrode for electric discharge surface treatment according to the present invention is used in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like electric discharge is caused to take place
25 between the electrode and a work in a dielectric fluid and, with

discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy.

Oil or the dielectric fluid for use in the electric discharge surface

- 5 treatment is caused to enter an internal space of the green compact formed by compression molding the metallic powder, the metal compound powder, or the ceramic powder.

An electrode for electric discharge surface treatment according to the present invention is used in an electric discharge surface

- 10 treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid and, with discharge energy, a coat is formed on a surface of the work, the coat
15 being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. After the green compact formed by compression molding the metallic powder, the metal compound powder, or the ceramic powder is subjected to a heating process, oil or the dielectric fluid for use in the
20 electric discharge surface treatment is caused to enter an internal space of the green compact.

- A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment that is used in an electric discharge surface treatment in which, by using a green compact
25 compression molded from a metallic powder, a metal compound powder,

or a conductive ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the discharge energy on the pulse, and includes selecting or dissolving of performing selection or dissolution so that a powder solid formed through coagulation of the metallic powder, the metal compound powder, or the conductive ceramic powder included in the green compact has a size smaller than a distance between the electrode and the work; and compression molding the selected or dissolved powder.

A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, the method, and includes finely crushing the metallic powder or the metal compound powder in a volatile solution; compression molding the finely-crushed metallic powder or metal compound powder in a state of being not completely dried; and volatilizing the volatile solution.

A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, and includes finely crushing the metallic powder or the metal compound powder in a liquid; compression molding the finely-crushed metallic powder in a state of being not completely dried; and removing the liquid from the finely-crushed metallic powder or metal compound powder.

A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, and includes finely crushing the metallic powder or the metal compound powder in a liquid; drying the finely-crushed

metallic powder or metallic powder; and compression molding the dried metallic powder.

A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for
5 use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of
10 the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, and includes finely crushing the metallic powder or the metal compound powder in a volatile solution; drying the finely-crushed metallic powder or metal compound powder in an inert
15 gas atmosphere; gradually oxidizing the dried metallic powder or metal compound powder; and compression molding the gradually-oxidized metallic powder or metal compound powder.

A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for
20 use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder or a metal compound powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid or air and, with discharge energy, a coat is formed on a surface of
25 the work, the coat being formed of an electrode material or a substance

resulting from reaction of the electrode material to the pulse-like discharge energy, and includes finely crushing the metallic powder or the metal compound powder in wax; and compressing and molding the finely-crushed metallic powder of metal compound powder.

5 A method according to the present invention is for manufacturing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like
10 electric discharge is caused to take place between the electrode and a work in a dielectric fluid and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, and includes forming a green compact by
15 compression molding the metallic powder, the metal compound powder, or the ceramic powder; and causing oil or the dielectric fluid for use in the electric discharge surface treatment to enter an internal space of the green compact.

 A method according to the present invention is for manufacturing
20 an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a
25 work in a dielectric fluid and, with discharge energy, a coat is formed on

a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy, and includes forming a green compact by compression molding the metallic powder, the metal compound powder, or the ceramic powder; heating the green compact; and causing oil or the dielectric fluid for use in the electric discharge surface treatment to enter an internal space of the green compact.

A method according to the present invention is for storing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a work in a dielectric fluid and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. The electrode for electric discharge surface treatment is stored by being immersed in oil or the dielectric solution for use in the electric discharge surface treatment.

A method according to the present invention is for storing an electrode for electric discharge surface treatment, the electrode for use in an electric discharge surface treatment in which, by using a green compact compression molded from a metallic powder, a metal compound powder, or a ceramic powder as the electrode, a pulse-like electric discharge is caused to take place between the electrode and a

work in a dielectric fluid and, with discharge energy, a coat is formed on a surface of the work, the coat being formed of an electrode material or a substance resulting from reaction of the electrode material to the pulse-like discharge energy. The electrode for electric discharge surface treatment is stored in a non-oxidative atmosphere that prevents oxidation of the metallic powder, the metal compound powder, or the ceramic powder.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic of an electric discharge surface treatment by an apparatus for electric discharge surface treatment; Fig. 2 is a flowchart of a process of manufacturing an electrode for electric discharge surface treatment; Fig. 3 is a cross-section of a mold for molding a powder; Fig. 4 is a photograph of a cross-section of an electrode manufactured without a sifting process; Fig. 5 is a photograph of a cross-section of an electrode manufactured with a sifting process; Fig. 6 is a graph depicting one example of a current waveform and a voltage waveform between poles during electric discharge surface treatment; Fig. 7 is a photograph of a coat formed by an electric discharge surface treatment using an electrode formed with a stellite powder sifted; Fig. 8 is a plot of a relation between a mesh size of a sifter and a thickness of a coat; Fig. 9 is a photograph of a surface of a coat formed of an electrode manufactured using a sifter of which a mesh size is 0.5 mm; Fig. 10 is a flowchart of manufacturing an electrode for electric discharge surface treatment with a metallic powder

or a ceramic powder less likely to be oxidized and having an average grain diameter of several μm ; Fig. 11 is a flowchart of manufacturing an electrode for electric discharge surface treatment with a metallic powder less likely to be oxidized and having an average grain diameter of several tens of μm ; Fig. 12 is a flowchart of manufacturing an electrode for electric discharge surface treatment with a metallic powder likely to be oxidized and having an average grain diameter of several tens of μm ; Fig. 13 is a photograph of a coat formed through an electric discharge surface treatment; Fig. 14 is a flowchart of a process of manufacturing another electrode for electric discharge surface treatment according to the present invention; Fig. 15 is a cross-section of a mold for molding a powder; Fig. 16 is a conceptual view of electric discharge surface treatment performed by the apparatus for electric discharge surface treatment; Fig. 17A depicts a voltage waveform (waveform of an interpole voltage) between an electrode 301 and a work 302 at a time of electric discharge; Fig. 17B depicts a current waveform of a current flowing through the apparatus for electric discharge surface treatment at a time of electric discharge; and Fig. 18 is a graph that illustrates increase in a weight of an electrode according to a time for soaking the electrode in a dielectric fluid.

BEST MODE FOR CARRYING OUT THE INVENTION

Exemplary embodiments of an electrode for electric discharge surface treatment, a method for manufacturing the same, and a method of storing the same according to the present invention are explained in

detail below with reference to the accompanying drawings. The present invention is not limited to the following description, and may be modified appropriately without departing from a scope of the present invention. Moreover, in the accompanying drawings, a scale of each member may differ for a purpose of easy understanding.

First Embodiment

In a first embodiment and a second embodiment described below, an electrode for electric discharge surface treatment with which formation of a dense thick coat by stable electric discharge without deteriorating surface roughness of the coat, and a method for manufacturing such an electrode are described.

First, an outline of the electric discharge surface treatment and an apparatus therefor used in the present invention is described. The outline described herein is commonly applied throughout the specification. Fig. 1 is a schematic of the electric discharge surface treatment by the apparatus for electric discharge surface treatment. An apparatus for electric discharge surface treatment 1 includes a work piece (hereinafter, "work") 11 on which a coat 14 is desired to be formed, an electrode for electric discharge surface treatment 12 for forming the coat 14 on the surface of the work 11, a power supply for electric discharge surface treatment 13 electrically connected to the work 11 and the electrode for electric discharge surface treatment 12 for supplying a voltage to both of the work 11 and the electrode 12 to cause arc discharge therebetween. When the electric discharge surface treatment is performed in a liquid, a work tank 16 is further

provided so that the work 11 and a portion of the electrode for electric discharge surface treatment 12 opposed to the work 11 make contact with an oil-based dielectric fluid 15, such as kerosene. Also, when the electric discharge surface treatment is performed in an atmosphere, the work 11 and the electrode for electric discharge surface treatment 12 are placed in a process atmosphere. In Fig. 1 and the following description, a case in which the electric discharge surface treatment is performed in a dielectric fluid is exemplarily depicted. Furthermore, in the following, the electrode for electric discharge surface treatment may be simply referred to as an electrode. Moreover, in the following, a distance between a surface of the electrode for electric discharge surface treatment 12 and a surface of the work 11 that are opposite to each other is referred to as an interpole distance.

Next, the electric discharge surface treatment by the apparatus for electric discharge surface treatment 1 having the structure as described above is described. The electric discharge surface treatment is performed by, for example, taking the work 11 on which the coat 14 is desired to be formed as a positive pole and the electrode for electric discharge surface treatment 12 as a negative pole using an electrode that is formed of a metal powder or a ceramic powder having an average grain diameter of 10 nanometers (nm) to several tens of μm to be a supply source of the coat 14. While the interpole distance is controlled by a control mechanism, which is not shown, so that these poles do not make contact with each other in the dielectric fluid 15, an electric discharge is caused to take place therebetween.

When an electric discharge occurs between the electrode for electric discharge surface treatment 12 and the work 11, heat due to the electric discharge causes a part of the work 11 and the electrode 12 to be melted. If an intermolecular bond of the electrode 12 is appropriate, a part (hereinafter, "electrode particle") 21 of the electrode 12 melted by a blast or an electrostatic force by the electric discharge is separated from the electrode 12, and is moved toward the surface of the work 11. Then, when reaching the surface of the work 11, the electrode particles 21 are re-coagulated into the coat 14. A part of the separated electrode particles 21 reacts with the dielectric fluid 15 or a component 22 in an atmosphere to form a substance 23, which also contributes to formation of the coat 14. In this manner, the coat 14 is formed on the surface of the work 11.

However, if the bonding between powder particles of the electrode 12 is strong, the electrode 12 is not peeled off by the blast or the electrostatic force by the electric discharge, thereby making it impossible to supply the electrode material to the work 11. That is, whether a thick coat can be formed by the electric discharge surface treatment depends on how the material is supplied from the electrode 12 and how the material supplied is melted on the surface of the work 11 and is bonded with the material of the material of the work 11. How the electrode material is supplied depends on how hard the electrode 12 is, that is, hardness.

A method for manufacturing the electrode for electric discharge surface treatment 12 fused in the electric discharge surface treatment is

described herein. Fig. 2 is a flowchart of a process of manufacturing the electrode for electric discharge surface treatment. First, a metallic powder or a ceramic powder that include a material that forms the coat 14 desired to be formed on the work 11 is crushed (step S1). If the
5 coat 14 is formed with several kinds of materials, powders of the materials are mixed at a desired ratio and crushed. For example, a metallic powder, a metallic alloy powder, or a ceramic spherical powder having an average grain diameter of several tens of μm that is available on the market is crushed by a mill apparatus, such as a ball mill, into
10 grains having an average grain diameter of 3 μm or less. Crushing may be performed in a liquid. In that case, the liquid is evaporated to dry the powder (step S2). Since the powder that is dried includes large solids formed due to coagulation of grains, to fragment the grains in such large solids, and to sufficiently mix the powder with wax at the
15 next step, the powder is sifted (step S3). For example, when a ceramic ball or a metal ball is put on a mesh of a shifter, on which the coagulated grains are left, and vibrated, the grains in the solids formed due to the coagulation are fragmented by a vibration energy and collision of the solids with the ball, and pass through the mesh. Only
20 grains that pass through the mesh are used in the following steps. Specifically, the powder including coagulated solids is put on a net of which a mesh size is smaller than the interpole distance.

Sifting of the powder crushed at step S3 is described herein. In the electric discharge surface treatment, a voltage applied between the
25 electrode for electric discharge surface treatment 12 and the work 11

for causing an electric discharge is normally within a range of 80 volts (V) to 300 V. When a voltage within this range is applied between the electrode for electric discharge surface treatment 12 and the work 11, the distance between the electrode 12 and the work 11 during the electric discharge surface treatment is of the order of 0.3 mm. As described above, in the electric discharge surface treatment, an arc discharge occurring across both poles causes the coagulated solids forming the electrode 12 to be separated from the electrode without changing a size of the coagulated solids. Here, if the size of the coagulated solids is below the interpole distance (0.3 mm or less), following electric discharge can be generated even if such a solid exists between the poles. Moreover, since the electric discharge occurs at a place in which the poles are close to each other, an electric discharge occurs at a place in which a solid exists, thereby crushing the solid by a thermal energy or explosion of the electric discharge.

However, if the size of the solid forming the electrode 12 is equal to or larger than the interpole distance (0.3 mm or more), an electric discharge causes the solids to be separated from the electrode 12 without changing the size of the solids. Such solids are deposited on the work 11 or are drifted in an interpole space between the electrode 12 and the work 11 filled with the dielectric fluid 15. As in the former case, if large solids are deposited, because an electric discharge occurs at a place in which the electrode 12 and the work 11 are close to each other, the electric discharge is concentrated on that place, and no electric discharge occurs at other places. As a result,

the coat 14 cannot be uniformly deposited on the surface of the work 11. In addition, the large solids cannot be completely melted by heat of the electric discharge. Therefore, the coat 14 becomes so brittle that the coat 14 is easily scraped off by hand. Furthermore, as in the latter
5 case, if large solids are drifted in the interpole space, a short circuit occurs between the electrode 12 and the work 11, thereby making it impossible to cause an electric discharge. Therefore, to form the coat 14 uniformly, and to achieve stable electric discharge, solids, which is formed due to the coagulation of the grain, having a size larger than the
10 interpole distance should not be present in the powder that forms the electrode 12. Such coagulation of grains likely to occur in a metallic powder and conductive ceramic, and is less likely to occur in a non-conductive powder. The coagulation of grains becomes more likely to occur as the average grain diameter of the powder is made
15 smaller. To avoid harmful effects due to solids caused by the coagulation of grains to be occurred during the electric discharge surface treatment, a process of sifting the powder coagulated at step S3 is required. For the purpose described above, a mesh size at the sifting should be smaller than the interpole distance.

20 Thereafter, to improve transmission of pressure from a press to a portion inside the powder at a subsequent pressing process, the powder is mixed with wax, such as paraffin, of approximately 1% to 10% in a weight percentage as required (step S4). If the powder is mixed with wax, formability improves, but the powder is again
25 surrounded by a liquid, causing coagulation by the action of an

intermolecular force or the electrostatic force and forming large solids. To fragmenting such solids formed with grains re-coagulated, the powder is sifted (step S5). A method of sifting at this step is carried out in a same manner as a method at step S3 described above.

5 Next, the powder obtained is molded by a compression press (step S6). Fig. 3 is a cross-section of a molder for molding the powder. A lower punch 104 is inserted from a lower portion of a hole formed on a mold (die) 105, and a space formed between the lower punch 104 and the mold (die) 105 is filled with the powder (when the powder is formed
10 of a plurality of constituents, powder mixture) 101. An upper punch 103 is then inserted from an upper portion of a hole formed on the mold (die) 105. Then, the powder 101 is compression molded with a pressure applied by a pressurizer or the like from both sides of the molder filled with the powder 101 described above by the upper punch
15 103 and the lower punch 104. In the following, the powder 101 that is compression molded is referred to as a green compact. At this time, when a high pressure is applied, the electrode 12 becomes hard, and when a low pressure is applied, the electrode 12 becomes soft.

Moreover, when a grain diameter of the powder 101 of the electrode
20 material is small, the electrode 12 becomes hard, and when the grain diameter of the powder 101 is large, the electrode 12 becomes soft.

The green compact is then removed from the molder and heated in a vacuum furnace or a furnace filled with a nitrogen atmosphere, thereby obtaining a conductive electrode (step S7). At the time of
25 heating, when a high heating temperature is applied, the electrode 12

becomes hard, and when a low heating temperature is applied, the electrode 12 becomes soft. By heating the green compact, it is also possible to decrease electric resistance of the electrode 12. Therefore, even if the powder is compression molded without mixing with wax at
5 step S4, heating is meaningful. By heating, bonding among powder particles in the green compact proceeds, thereby producing an electrode for electric discharge surface treatment 12 that has conductivity.

The electrode for electric discharge surface treatment 12 can be
10 molded even when the crushing process at step S1 described above is omitted, that is, even when the powder having an average grain diameter of several tens of μm is used as it is or when the sifting process at step S3 is omitted, and large solids as large as 0.3 mm or more are present. However, non-uniformity in hardness occurs in the
15 electrode 12 such that hardness of a surface of the electrode is high and hardness of a center portion is low, which is not preferable. Moreover, in this electrode 12, the center portion is consumed through the electric discharge, but portions near the surface are not consumed. Thus, deposition to the surface of the work 11 is not proceeded, which
20 is not preferable, either. In other words, the electrode material at a portion of a perimeter of the electrode 12 is too hard to be supplied, thereby causing the surface of the work 11 to be removed. On the contrary, since the center portion of the electrode 12 is brittle, it is consumed quickly after the process is started. As a result, the surface
25 of the electrode 12 becomes such that its perimeter protrudes and its

center portion is recessed. Since an electric discharge occurs only at the perimeter having a small interpole distance, removal of the surface of the work 11 proceeds, thereby making deposition impossible.

Furthermore, powders of Co, Ni (nickel), which are less likely to
5 be oxidized, an alloy or oxide thereof, or ceramics having an average grain diameter thereof 3 μm or less are usually available on the market. Therefore, when any of these powders is used, the crushing process at step S1 and the drying process at step S2 described above may be omitted.

10 In the following, the present invention is described in more detail based on specific embodiments.

First, a stellite powder (a Co alloy having an average grain diameter of 50 μm), which is less likely to be oxidized under temperatures of 800 degrees Celsius ($^{\circ}\text{C}$) or lower was crushed by a
15 vibrating mill to bring an average grain diameter to be 1.5 μm , and was then dried. A stellite used herein has a composition including 25 weight % Cr (chromium), 10 weight % Ni (nickel), 7 weight % W (tungsten), 0.5 weight % C (carbon), and Co for the rest.

Also, instead of the stellite having the above structure, a stellite
20 having a composition including 28 weight % Mo (molybdenum), 17 weight % Cr, 3 weight % Si (silicon), and Co for the rest, or a stellite having a composition including 28 weight % Cr, 5 weight % Ni, 19 weight % W, and Co for the rest may be used.

Electrodes were manufactured using a non-sifted powder, and a
25 sifted powder respectively. The dimensions of the mold used at the

time of pressing were 18.2 mm in diameter and 30.5 mm in length. By using such a mold, the stellite powder was compression molded at a predetermined pressure of the press, and was then heated.

Of the processes of manufacturing an electrode for electric
5 discharge surface treatment described above, the sifting process after drying (step S3) and the sifting process after mixing paraffin (step S5) were omitted to manufacture an electrode, a section photograph (scaling: 35 times) of which is shown in Fig. 4.

To fragment the powder coagulated in the course of drying, a
10 sifter having a mesh size of 0.15 mm was used for fine crushing and, after mixing with paraffin, a sifter having a mesh size of 0.3 mm was used to manufacture an electrode. A section photograph of the electrode thus manufactured is shown in Fig. 5.

First, the electrode shown in Fig. 4 is examined. A portion
15 appearing white is a large solid, and it can be seen that many of such portions are present in a mixed manner. When the white portion is scratched by a pin, the portion appearing white is separated as a solid.

On the other hand, when the electrode shown in Fig. 5 is examined, it is apparent that no such solid as seen in Fig. 4 is present.

20 Using these electrodes, electric discharge surface treatment was performed under various electric-discharge pulse conditions approximately to the extent that a peak current value $i_e=5$ amperes (A) to 20 A, and an electric-discharge duration (electric discharge pulse width) $t_e=4$ microseconds (μs) to 100 μs . As for polarities, the
25 electrode side was used as a minus polarity, while the work side was

used as a plus polarity.

As a result, in the electric discharge surface treatment using the electrode manufactured with the sifted stellite powder, a coat having a film thickness of the order of 0.1 mm was able to be formed under any of the electric-discharge pulse conditions with a processing time of approximately five minutes. On the other hand, in the case of the electric discharge surface treatment using the electrode manufactured with the non-sifted stellite powder, a short circuit occurred to unstabilize the electric discharge, thereby preventing the process from proceeding, and making a deposition process impossible.

Thus, as described above, it was confirmed that there is the harmful effect due to the large solids of the stellite powder that is separated from the electrode without changing its size, and that is then deposited on the work or drifted between the poles filled with the dielectric fluid between the electrode and the work.

Fig. 6 is a graph depicting one example of a current waveform and a voltage waveform between the poles during the electric discharge surface treatment. A waveform V shown in Fig. 6 at a portion near a top of the graph represents a voltage, and a waveform I shown in Fig. 6 at a portion near a bottom of the graph represents a current. On a vertical axis on a right end, an underline drawn under 1 represents 0 A, while an underline drawn under 3 represents 0 V. A horizontal axis represents time in 100 millisecond (ms) divisions, while vertical axes represent in 50 V divisions on top and in 5 A divisions on bottom. A waveform W1 shown on the left side from approximately the center of

the drawing represents a waveform when a current is successfully generated with the application of a voltage. As for a waveform W2 shown on the right side from approximately the center of the drawing, a current waveform changes, while a voltage waveform does not change.

- 5 When a current flows with a voltage being unable to be applied, a short circuit occurs between the poles. Therefore, it can be determined that the state represented by the waveform on the right side from approximately the center of the drawing is a short-circuit state.

Results similar to the above were obtained when an electric
10 discharge surface treatment was performed using an electrode manufactured by sifting the powder after drying, fragmenting coagulated solids, and omitting a sifting process after mixing with paraffin.

Also when an electrode manufactured by sifting the stellite powder to eliminate large solids was used to perform a process (electric
15 discharge surface treatment) under other conditions (electric-discharge pulse conditions), it was possible to achieve a stable electric discharge and to form a coat having a film thickness of the order of 0.1 mm with the process (electric discharge surface treatment) of five minutes.

The coat formed by the electric discharge surface treatment
20 using the electrode manufactured with the sifted stellite powder is shown in Fig. 7. Process conditions (electric-discharge pulse conditions) applied here are a peak current value $i_e=12$ A, and an electric-discharge duration $t_e=64$ ms. When a short circuit occurs between the poles, a large solid may be deposited on the work or a hole
25 may be formed on the coat. However, in Fig. 7, no projections and

depressions were observed on the coat, and therefore it is evident that the coat was formed with a stable electric discharge.

According to the first embodiment, in the formation of an electrode by compression molding using a metallic powder or a ceramic powder, the electrode for electric discharge surface treatment manufactured does not include large solids formed due to the coagulation of the powder, specifically, those larger than a distance between the electrode and the work at the time of the electric discharge surface treatment. This can prevent situations such as large solids are deposited on the work or drifted between the poles during the electric discharge surface treatment, thereby achieving a stable electric discharge. As a result, a thick coat with a smooth surface can be obtained.

When a powder having an average grain diameter of 3 μm or less is directly obtained from the market for manufacturing an electrode, the drying process (step S2) and the subsequent sifting process (step S3) are not required. Also, a powder produced by water atomization or the like has a spherical shape, and has a high moldability at the time of compression and shaping even without paraffin to be mixed. Therefore, when such a powder is used to manufacture an electrode, the paraffin mixing process (step S4) and the subsequent sifting process (step S5) are not required.

Second Embodiment

In the second embodiment, a Co powder having an average grain diameter of 1 mm was used to study a relation between the size of

a mesh of a sifter and the coat thickness.

A sifted powder was used herein, the dimensions of a mold were 18.2 mm in diameter and 30.5 mm in length, and an electrode produced by compression molding the powder at a predetermined pressure of a
5 press and then by heating a resultant compact was used. Process conditions are similar to those in the first embodiment, and the processing time was 10 minutes.

The relation between the mesh size of the sifter and the coat thickness is shown in Fig. 8. The coat thickness shown in Fig. 8
10 represents an average value of the coat thickness measured at five points on the coat. It is apparent from Fig. 8 that, when the mesh size exceeded 0.3 mm, the coat thickness decreased with respect to a process time, and when the mesh size was over 0.5 mm, no coat was able to be deposited.

15 One reason for this is thought to be that, when the mesh size exceeds 0.3 mm, large solids that cannot possibly be dissolved by the electric discharge begin to appear between the poles and cause a short circuit or instability in the electric discharge, thereby decreasing the number of electric discharges and reducing the coat thickness. As
20 described in the first embodiment, this can be understood from the interpole distance between the electrode and the work.

A photograph of the surface of the coat based on an electrode manufactured using a sifter having a mesh size of 0.5 mm is shown in Fig. 9. From Fig. 9, it is apparent that small protruding particles A
25 appear to be attached on the coat because large solids of the stellite

powder cause a short circuit between the poles, thereby causing a large current to flow.

Also, an electric discharge occurs at a portion in which the electrode and the work are close to each other. It can therefore be
5 concluded that, at portions other than the protruding portion, no electric discharge occur, and therefore, no coat can be formed.

According to the second embodiment, if the mesh size of the sifter is set as 0.3 mm, which is the distance between the electrode and the work, or smaller, it is possible to obtain a stable electric discharge
10 and deposition of a thick coat.

Third Embodiment

In a third embodiment and fourth and fifth embodiments following the third embodiment, description is made to an electrode for electric discharge surface treatment that is used in forming a metallic
15 coat by the electric discharge surface treatment, and that is formed with a powder of metal likely to be oxidized or an alloy including metal likely to be oxidized, and a method for manufacturing such an electrode.

The principle of the electric discharge surface treatment has been described in the first embodiment, and is therefore not described
20 herein.

Next, a method for manufacturing an electrode for electric discharge surface treatment is described. First, a method for manufacturing an electrode for electric discharge surface treatment manufactured with a metallic powder or a ceramic powder that are less
25 likely to be oxidized as an electrode material is described. Fig. 10 is a

flowchart of manufacturing such electrode for electric discharge surface treatment.

First, a powder of metal, a metallic alloy, or ceramics having a constituent of a coat desired to be formed on the work is purchased
5 (step S11). Such a powder is available on the market and is a spherical powder of metal or ceramics that are less likely to be oxidized and that have an average grain diameter of several μm .

Then, to improve transmission of pressure from the press to a portion inside of the powder at a subsequent pressing process, the
10 metallic powder, the metal alloy powder, or the ceramic powder is mixed with wax, such as paraffin, of approximately 1% to 10% in weight percentage as required (step S12).

If the powder and wax are mixed together, moldability improves. However, surrounding of the powder particles are again covered with a
15 liquid, thereby causing coagulation by the action of an intermolecular force or the electrostatic force, and forming large solids. Thus, solids formed again due to the coagulation are sifted to be fragmented (step S13).

Next, the powder obtained is compression molded by a
20 compression press (step S14). Compression molding of the powder is performed using a molder in the manner described in the first embodiment described above. In the following, a solid obtained by compression molding is referred to as a green compact.

Thereafter, the green compact is removed from the molder, and
25 is then heated in a vacuum furnace or a furnace filled with the nitrogen

atmosphere, thereby obtaining a conductive electrode (step S15). At the time of heating, when a high heating temperature is applied, the electrode becomes hard, and when a low heating temperature is applied, the electrode becomes soft. By heating the green compact, it is possible to decrease the electric resistance of the electrode.

Therefore, even if the powder is compression molded without mixing with wax at step S12, heating is meaningful. With this, bonding among powder particles in the green compact proceeds, thereby obtaining an electrode for electric discharge surface treatment that has conductive.

10 An electrode for electric discharge surface treatment can be manufactured in the manner as described above using a metallic powder or a ceramic powder that are less likely to be oxidized as an electrode material.

 However, not all kinds of metallic powders and ceramic powders that are less likely to be oxidized and that are available on the market are those having an average grain diameter of several μm . Moreover, metallic powders that are likely to be oxidized and that are available on the market are limited to those having an average grain diameter of 10 μm or more. In general, as the grain diameter of the powder decreases, a ratio of the surface area to the volume of the powder increases. In other words, a heat capacity of the powder decreases, and the powder becomes very sensitive to energy. Therefore, for example, when a metallic powder likely to be oxidized is surrounded by oxygen, the powder is oxidized very quickly to a portion inside the powder, thereby losing its properties as metal, such as conductivity and

ductility. Furthermore, oxidation of the powder may explosively proceed. That is why the metallic powder likely to be oxidized and available on the market is limited to those having a large average grain diameter of 10 μm or more. The metal likely to be oxidized includes Cr (chromium), Al (aluminum), and Ti (titanium). However, even when any of such metallic powders likely to be oxidized is used as the electrode material, if the powder is compacted by compression molding to form an electrode, the surface of the electrode is oxidized, but the inside thereof is not so oxidized. In addition, the powder can be prevented from being explosively oxidized.

A method for manufacturing the electrode for electric discharge surface treatment formed with a commercially-available metallic powder that has an average grain diameter of several tens of μm , and that is less likely to be oxidized is described with reference to a flowchart shown in Fig. 11. First, the commercially-available metallic powder having an average grain diameter of several tens of μm and less likely to be oxidized is crushed with a mill, such as a ball mill, in volatile solvent of acetone or the like into particles having an average grain diameter of 3 μm or less (step S21). Then, the solvent is vaporized to dry the powder (step S22). Since the powder dried has large solids formed due to the coagulation of grains, to fragment these large solids and to sufficiently mix the powder with wax at a next step, the powder is sifted (step S23).

Thereafter, to improve transmission of pressure from the press to a portion inside of the powder at a subsequent pressing process, the

powder is mixed with wax, such as paraffin, of approximately 1% to 10% in weight percentage as required (step S24). If the powder is mixed with wax, formability improves, but the powder is again surrounded by a liquid, thereby causing the coagulation by the action of an intermolecular force or the electrostatic force, and forming large solids. To fragment the solids formed due to the re-coagulation, the powder is sifted (step S25).

Next, the powder obtained is compression molded by a compression press (step S26). Compression molding of the powder is performed using a molder in the manner described in the first embodiment described above. In the following, a solid of the powder obtained by compression molding is referred to as a green compact.

The green compact is then removed from the molder, and is then heated in a vacuum furnace or a furnace filled with a nitrogen atmosphere, thereby obtaining a conductive electrode (step S27). At the time of heating, when a high heating temperature is applied, the electrode becomes hard, and when a low heating temperature is applied, the electrode becomes soft. By heating the green compact, it is possible to decrease electric resistance of the electrode 12.

Therefore, even if the powder is compression molded without mixing with wax at step S14, heating is meaningful. With this, bonding among powder particles in the green compact proceeds, thereby manufacturing an electrode for electric discharge surface treatment that has conductivity.

An electrode for electric discharge surface treatment can be

manufactured in the manner as described above using a commercially-available metallic powder having an average grain diameter of several tens of μm and less likely to be oxidized.

However, when an electrode is manufactured by this method by using a metallic powder likely to be oxidized, the metallic powder is oxidized in the drying process described above. Therefore, this manufacturing method cannot be directly applied to a process of manufacturing an electrode formed with a metallic powder likely to be oxidized.

Fig. 12 is a flowchart of manufacturing an electrode for electric discharge surface treatment according to the present invention. A commercially-available metallic powder likely to be oxidized has an average grain diameter of several tens of μm .

First, the commercially-available metallic powder having an average grain diameter of several tens of μm and likely to be oxidized is crushed with a mill, such as a ball mill, in volatile alcohol or solvent (hereinafter, "solvent medium") into grains having an average grain diameter of 3 μm or less (step S31).

After crushing, the metallic powder and the solvent medium are put in a container for separation into solid and liquid. Specifically, the electrode powder, that is, the metallic powder, is caused to settle in the solvent medium for removal of a supernatant of the solvent medium to obtain only the metallic powder (step S32). The metallic powder at this time is not oxidized because the solvent medium is sufficiently contained.

Next, the metallic powder obtained is compression molded by a compression press without being dried (step S33). In the following, a solid obtained by compression molding the metallic powder is referred to as a green compact. Compression molding of the powder is

5 performed using a molder in the manner described in the first embodiment described above. In the present invention, the metallic powder is left being pressed by the press until a shape of an electrode is obtained, while volatilizing the solvent medium. When a liquid having a low boiling point, such as acetone, is used as the solvent

10 medium, the solvent medium volatilizes within no more than several minutes.

In this process, since what is required is that the solvent medium is dried to the extent that the green compact can keep its shape, the solvent medium does not have to be completely volatilized.

15 Therefore, if the green compact has been dried to an extent sufficient to keep its shape, the green compact can be extracted from the molder before the solvent medium is completely dried.

Where there is no oxidized coat on the surface of the metallic powder, particles of the metallic powder forms a metallic bond.

20 Therefore, when a metallic powder is used as an electrode material, an electrode having strength to some extent can be molded. Moreover, even with a metallic powder likely to be oxidized, the metallic power is not oxidized as far as a portion inside the metallic powder if compacted. This is because each metallic powder particle is bonded with its many

25 surrounding particles to have an increased ratio of the volume to the

surface area (this is virtually the same as having an increased grain diameter), and therefore becomes insensitive to heat generated when the metallic powder is oxidized.

Furthermore, when the electrode (compact) is dried, a little
5 space is left in a portion occupied by the solvent medium, that is, a portion between metal particles in the electrode. The volume of the space and oxygen that is present therein are so small that oxidation of the metallic powder does not go beyond oxidation of its surface.

Then, once an oxidized coat is formed on the surface of the
10 metallic powder, the metallic powder is in an extremely chemically-stable condition (in a high entropy condition). Therefore, even when the metallic powder having the oxidized coat formed thereon is exposed in air, a portion inside is not oxidized. Therefore, by performing steps S31 to S33 described above, oxidation of the metallic
15 powder can be prevented from going beyond the oxidation on the surface.

Thereafter, heating is performed in a vacuum furnace or a furnace filled with a nitrogen atmosphere, thereby producing a conductive electrode (step S34). Even when the green compact is not
20 completely dried during pressing, it is possible to make the solvent completely volatile during the heating process.

An electrode for electric discharge surface treatment can be manufactured in the manner as described above using a commercially-available metallic powder that has an average grain
25 diameter of several μm and that is likely to be oxidized.

In the manufacturing method described above, if the mold is appropriately heated (approximately at a boiling point of a solvent medium) during pressing, it is possible to reduce time required for volatilizing the solvent medium. For example, when acetone is used as the solvent medium, it is preferable that the mold be heated at the order of 60°C. If the mold is heated at such high temperatures as 300°C to 1000°C, the metallic powder is melted, or bonding of the metallic powder proceeds too much. Such problems do not occur with the temperature of the order of degrees above.

Also, even when the solvent medium is completely volatilized at the stage of pressing the metallic powder, the green compact formed of the metal likely to be oxidized is still in a solid state. Therefore, each metallic powder particle forming the green compact is bonded with its many surrounding metallic powder particles to have an increased ratio of the volume to the surface area (this is virtually the same as having an increased grain diameter), and therefore, becomes insensitive to heat generated when the metallic powder is oxidized. Thus, the portion inside of the powder is not oxidized.

If a metallic powder having a low moldability is used, such a metallic powder including acetone or ethanol should be mixed with wax before compression molding. Moldability can be improved if the powder is mixed with wax, such as paraffin, of approximately 1% to 10% in weight percentage to improve the transmission of pressure from the press to a portion inside of the powder at the time of a pressing process. However, when wax is used, acetone may dissolve the wax.

Therefore, it is preferable to use alcohol, such as ethanol, at the time of crushing.

After the wax is mixed in the metallic powder including acetone or ethanol, sifting is performed. The powder obtained is compression
 5 molded by a compression press in a manner similar to that above, and is then heated by a vacuum furnace or a furnace filled with a nitrogen atmosphere, thereby manufacturing a conductive electrode. The wax in the electrode is removed at the time of heating.

Also, if the metallic powder is crushed in wax, no alcohol or the
 10 like needs to be used. However, when wax is used for crushing by a ball mill or the like, wax reduces a ball speed because it generally has a high viscosity, thereby reducing the crushing capability. Therefore, as for a bead mill, it is required to increase rotation speed of the mill to obtain approximately the same crushing capability as that of the
 15 crushing capability obtained when acetone or ethanol is used. As for a vibration mill, it is required to increase its amplitude and vibration speed.

Next, examples of a solvent medium to be volatilized are shown in Table 1.

20

Table 1

Substance	Boiling point
Toluene	110.6
Xylene	139.1
MEK	79.6
Normal hexane	67
Isooctane	99.2
Benzene	80.1
Acetone	56

Ethanol	78
Propanol	97.2
Butanol	128.8

The solvent media shown in Table 1 are examples of a solvent medium usable for the present invention. Therefore, in this invention, any solvent medium can be used as long as it has a boiling point of
 5 around 100°C, and as long as the solvent medium does not corrode a container or a press used in crushing. However, in consideration of environment, alcohols, such as ethanol, are preferable.

In addition, if a solvent medium having a boiling point near 60°C is used, because such solvent medium quickly volatilizes, a time
 10 required for volatilizing at the time of pressing can be shortened. However, an operation between processes has to be done quickly. If the operation requires some time, it is preferable to use a solvent medium having a boiling point as high as possible, although the time required for volatilizing is thereby lengthened.

15 Next, an example of manufacturing an electrode for electric discharge surface treatment using Cr (chromium) as metal likely to be oxidized is described. In general, a commercially-available Cr powder has an average grain diameter of the order of 10 μm . Such a powder was first crushed with a vibration-type ball mill. Crushing conditions
 20 are depicted in Tables 2 and 3.

Table 2

Ball material	ZrO ₂
Diameter	$\phi 1/2$

Table 3

Pot material	ZrO ₂
Pot capacity	3.6L
Powdering method	Wet
Material injection amount	1 kg
Solvent medium	Ethanol

The material of a ball and a container of the vibration-type ball mill was ZrO₂, and a size of the ball was 1/2 inch. 1 kilogram (kg) of a Cr powder was put in a 3.6-liter container, and the container was filled
 5 with ethanol. The container was then vibrated to crush the Cr powder. As a result, the average grain diameter of the Cr powder was able to be reduced to 2.0 μm .

Next, the Cr powder crushed was extracted together with ethanol to let the Cr powder precipitate in ethanol. The Cr powder was
 10 allowed to precipitate for approximately 1 hour, thereby making it possible to separate the Cr powder and ethanol. Thereafter, a supernatant of ethanol was removed, thereby obtaining a Cr powder containing a large amount of ethanol.

Next, approximately 32 grams (g) of the Cr powder obtained was
 15 taken out to be compression molded. A mold having dimensions of 18.2 mm in diameter and 30.5 mm in length was used. With the mold, the state in which a predetermined pressure of the press was applied to the Cr powder was kept for approximately 5 minutes, thereby evaporating ethanol and making a green compact of the Cr powder to
 20 be enough hard to keep a shape.

Then, this compact was heated in a vacuum furnace at a predetermined heating temperature for approximately 4 hours to

manufacture a conductive electrode. Ethanol was completely evaporated during heating and was removed from the electrode.

Through the processes described above, it was possible to manufacture a conductive Cr electrode with oxidation of the Cr powder proceeding only on a surface and without oxidation proceeding to a portion inside of the Cr powder.

Next, a depositing process (electric discharge surface treatment) was performed using the electrode for electric discharge surface treatment manufactured with the Cr powder as the electrode material. Process conditions were such that the peak current value $i_e = 12$ A, and the electric-discharge duration (electric discharge pulse width) $t_e =$ approximately 8 μ s. As a result of the process (the electric discharge surface treatment) performing for 3 minutes, a coat having a thickness of approximately 1 mm was able to be formed. A photograph of the coat formed by the electric discharge surface treatment is depicted in Fig. 13. In the photograph shown in Fig. 13, a thick coat of approximately 1 mm formed is shown. Concentration of the electric discharge or occurrence of a short circuit was not observed on a surface of the coat, and therefore, it can be assumed that a stable electric discharge had proceeded.

Effects similar to those in the case of Cr described above were able to be obtained with Ti or Al, for example, which is metal likely to be oxidized.

According to the third embodiment, even when a metallic powder that is likely to be oxidized, and that has a grain diameter

thereof 3 μm or less is used, an electrode for electric discharge surface treatment can be manufactured with oxidation of the metallic powder proceeding only on a surface and without oxidation proceeding at a portion inside of the metallic powder. Thus, metal likely to be oxidized
5 can be selected as an electrode material for an electrode for electric discharge surface treatment, and a thick coat of metal likely to be oxidized, such as Ti, Al, or Cr, can be formed in a non-oxidized state by an electric discharge surface treatment.

When a non-oxidized coat is oxidized in high-temperature
10 environments, abrasion resistance and heat resistance can be obtained. Such coat characteristics enables to expand the technical field to which the coat is applicable.

Fourth Embodiment

In the fourth embodiment, a method for manufacturing another
15 electrode for electric discharge surface treatment according to the present invention is described. Fig. 14 is a flowchart of manufacturing the electrode for electric discharge surface treatment. A commercially-available metallic powder likely to be oxidized has an average grain diameter of approximately 10 μm .

20 First, a commercially-available metallic powder likely to be oxidized and having an average grain diameter of approximately 10 μm is crushed in acetone, which is highly volatile, with a mill, such as a ball mill apparatus, into particles having an average grain diameter of 3 μm or less (step S41).

25 Then, the metallic crushed powder is dried in a nitrogen

atmosphere or an inert gas atmosphere. Next, only a surface of the powder is oxidized while slightly taking air in (step S42). When the metallic powder likely to be oxidized is exposed to oxygen, the metallic powder is oxidized, as a matter of course. However, if there is not
5 enough oxygen to oxide a portion inside the metallic powder, oxidation of the metallic powder proceeds only on the surface of the powder. Once an oxidized coat is formed on the surface of the metallic powder, the metallic powder is in an extremely chemically-stable condition (in a high entropy condition). Therefore, even when the metallic powder
10 having the oxidized coat formed thereon is exposed in air, the portion inside is not oxidized. Such a process of forming an oxidized coat on a metallic powder is referred to as a gradual oxidizing process.

When the metallic powder is exposed to air suddenly, oxidation proceeds to a portion at a center of the metallic powder. When the
15 portion inside of the metallic powder is oxidized, the metallic powder loses its conductivity, and never forms an electric-dischargeable electrode even if the metallic powder is pressed and heated. However, when oxidation of the metallic powder proceeds only on the surface of the powder, particles are pressed to each other by a press to break the
20 oxidized coat, thereby allowing a metallic bonding among metallic powder particles. Therefore, if oxidation of the metallic powder proceeds only on the surface of the powder, a conductive electrode can be produced. A metallic bonding between metallic powder particles can be promoted also in a heating process described below.

25 The metallic powder after drying may form large solids due to

the coagulation of particles. To improve the transmission of pressure of the press to the portion inside the powder at the pressing process, the powder is mixed with wax, such as paraffin, of approximately 1% to 10% in weight percentage before pressing, thereby making it possible
5 to improve formability of the metallic powder. For this purpose, the metallic powder after drying is sifted so that wax, such as paraffin, and the metallic powder are mixed well with each other, thereby clearing the coagulation of the metallic powder (step S43).

Thereafter, to improve the transmission of pressure from the
10 press to the portion inside the powder at the pressing process, the powder is mixed with wax, such as paraffin, of approximately 1% to 10% in weight percentage as required before pressing (step S44). Mixing the powder with wax improves formability, but the powder is again surrounded by a liquid, thereby causing the coagulation by the
15 action of the intermolecular force or the electrostatic force, and forming large solids. To fragment the solids formed due to the re-coagulation, the powder is sifted (step S45).

Next, the powder obtained is molded by a compression press (step S46). Compression molding the powder is performed using a
20 molder in the manner described in the first embodiment described above. In the following, a solid of the powder obtained by compression molding is referred to as a green compact.

Thereafter, the green compact is removed from the molder, and is then heated in a vacuum furnace or a furnace filled with a nitrogen
25 atmosphere, thereby obtaining a conductive electrode (step S47).

An electrode for electric discharge surface treatment can be manufactured in the manner as described above with, as an electrode material, a commercially-available metallic powder that has an average grain diameter of approximately 10 μm , and that is likely to be oxidized.

5 Next, an example in which Cr (chromium) is used as metal likely to be oxidized to manufacture, by the manufacturing method as described above, an electrode for electric discharge surface treatment is described below. In general, a Cr powder commercially available has an average grain diameter of the order of 10 μm . Such a powder
10 was first crushed by a vibration-type ball mill. Crushing conditions were similar to those in the third embodiment described above, and crushing was performed under conditions similar to those shown in Tables 1 and 2. That is, the material of a ball and a container in the vibration-type ball mill was ZrO_2 , and the size of the ball was 1/2 inch.
15 1 kg of a Cr powder was put in a 3.6-liter container, and the container was filled with acetone as a solvent medium. The container was then vibrated to crush the Cr powder. As a result, the average grain diameter of the Cr powder was able to be reduced to 2.0 μm .

 Next, the Cr powder after crushing was put in a container and
20 placed in a drying apparatus, and then was dried by being cooled with chiller water at a temperature of approximately 10°C. The Cr powder dried weighed approximately 1 kg. Furthermore, the Cr powder dried was uniformly spread at a bottom of an approximately 100-liter container. The container was first filled with nitrogen, and then air is
25 injected at 0.2 liter (L) per minute in the container so that a volume ratio

of nitrogen and air was 9:1. Then, in this state, the temperature inside the container was kept at 60°C and left for approximately 5 hours. In this manner, the surface of the Cr powder crushed was slightly oxidized. In other words, the surface of the Cr powder crushed was gradually
5 oxidized.

If a pressure of a press is lowered at the time of compressing and molding the Cr powder, electric resistance of the electrode for electric discharge surface treatment manufactured is of the order of 10 kilo-ohms ($k\Omega$), and therefore, an electric discharge cannot be achieved
10 even by performing an electric discharge surface treatment using the electrode for electric discharge surface treatment. However, if the pressure of the press is increased to some extent at the time of compressing and molding, the oxidized coat of the Cr powder is broken, thereby reducing the electric resistance of the electrode manufactured
15 to approximately 10.

With an oxidized coat being formed on the surface of the metallic powder, the metallic powder is chemically stabilized, and is therefore, easy to handle as normal ceramics. With such a chemically-stable metallic powder, an electrode for electric discharge
20 surface treatment can be molded by a manufacturing method similar to the conventional method.

However, an oxide is generally non-conductive. Therefore, a conductive electrode for electric discharge surface treatment cannot be manufactured unless the oxidized coat of the metallic powder is broken
25 by heating or pressing. With an electrode for electric discharge

surface treatment manufactured without the oxidized coat of the metallic powder being broken, that is, a non-conductive electrode for electric discharge surface treatment, an electric discharge cannot be generated, as a matter of course. To solve the problem, the oxidized
5 coat of the metallic powder should be broken by applying a predetermined pressure at the time of compression molding, thereby causing a metallic bond between metallic powders. As a result, the electrode manufactured has conductivity, and with the electrode, it is possible to generate an electric discharge, thereby making the electric
10 discharge surface treatment possible.

Thereafter, to fragment the Cr powder coagulated through the drying process, a sifter having a mesh size of 0.15 mm was used to finely crush the Cr powder. Then, the Cr powder finely-crushed was mixed with paraffin of 8% in weight percentage, and was then finely
15 crushed again by a sifter having a mesh size of 0.05 mm.

Next, approximately 32 g of the Cr powder obtained was taken out to be compression molded. A mold having dimensions of 18.2 mm in diameter and 30.5 mm in length was used. Then, the green compact was heated in a vacuum furnace at a predetermined heating
20 temperature for a predetermined time to manufacture a conductive electrode.

With the processes described above, it was possible to obtain a conductive Cr electrode without oxidation proceeding to a portion inside of the Cr powder and with oxidation of the Cr powder proceeding only
25 on a surface.

Next, a depositing process (electric discharge surface treatment) was performed using the electrode for electric discharge surface treatment manufacture with this Cr powder as the electrode material. Process conditions were such that the peak current value
5 $i_e=12$ A, and the electric-discharge duration (electric discharge pulse width) t_e =approximately 8 μ s. As a result of the process (the electric discharge surface treatment) performing for 3 minutes, a coat having a thickness of approximately 1 mm was able to be formed.

Concentration of the electric discharge or occurrence of a short circuit
10 was not observed on a surface of the coat, and therefore, it can be assumed that a stable electric discharge had proceeded.

In the foregoing, description has been made to a case of manufacturing an electrode for electric discharge surface treatment by using a metallic powder likely to be oxidized. A Co alloy powder having
15 a lubrication property and corrosion resistance under a high-temperature environment is also oxidized if including metal likely to be oxidized. Therefore, the present invention is applied also to the case of manufacturing an electrode for electric discharge surface treatment using an alloy powder that includes metal likely to be oxidized
20 and has an average grain diameter one of 1 μ m, thereby making it possible to manufacture a conductive alloy electrode without oxidation proceeding to a portion inside of the alloy powder and with oxidation of the alloy powder proceeding only on a surface.

As described above, according to the fourth embodiment, even
25 when a metallic powder likely to be oxidized and having a grain

diameter thereof 3 μm or less is used, an electrode for electric discharge surface treatment can be manufactured without oxidation proceeding to the portion inside of the metallic powder and with oxidation of the metallic powder proceeding only to the surface. Thus, metal likely to be oxidized can be selected as an electrode material for an electrode for electric discharge surface treatment, and a thick coat of metal likely to be oxidized, such as Ti, Al, or Cr, can be formed as being in a non-oxidized state by the electric discharge surface treatment.

Also, according to the fourth embodiment, since a gradual oxidizing process is performed after crushing the powder, an oxidized coat is formed on the surface of the metallic powder likely to be oxidized, thereby obtaining a chemically-stable metallic powder. As a result, the powder becomes easy to handle as ceramics. With such a chemically-stable metallic powder, even if it is a metallic powder likely to be oxidized, an electrode for electric discharge surface treatment can be manufactured by a manufacturing method similar to the conventional method.

Fifth Embodiment

In the fifth embodiment, a method for manufacturing an electrode for electric discharge surface treatment using a powder finely crushed in wax is described.

A heating wire is wound around a side surface of a container of a mill container, such as a ball mill apparatus. An input to the heating wire is adjusted such that an inner wall of the container becomes at a temperature of 60°C to 80°C. Alcohol (propanol or butanol) having a

boiling point of 100°C or higher is then put in the container. Next, wax of 5 weight % to 10 weight % in weight percentage with respect to a powder to be crushed is put in the container. Wax having a melting point of approximately 50°C is used. After wax is sufficiently melted by
5 being stirred in the container, a ball made of zirconia for crushing and the powder to be crushed are put in the container. The amount of each input is similar to that in the third embodiment. The kinematic viscosity of the melted wax is approximately three times as high as the kinematic viscosity of alcohol, thereby increasing an influence the solvent medium
10 on the ball in resistance. To complete crushing within a time as short as the time required for crushing when alcohol is used, it is required to increase the number of vibrations to some extent.

After the powder is crushed to have a desired grain diameter, vibration is stopped. Next, the input to the heating wire is increased to
15 bring the temperature approximately to the boiling point of alcohol to volatilize alcohol. At this time, caution is required so that the temperature is kept below 230°C, which is the flash point of wax. Upon completion of volatilization of alcohol (the weights of the input powder and wax are known), heating process ends. When the heating process
20 is finished, wax coagulates due to a decrease in temperature. At this time, coagulation of wax proceeds while the powder and wax are stirred. When the temperature becomes as low as approximately a room temperature, an electrode is completed through processes identical to the sifting process at step S45 shown in Fig. 14 according to the fourth
25 embodiment.

According to the fifth embodiment, by performing crushing in wax, the powder is covered with wax even after alcohol is dried, and therefore does not make contact with air, thereby obtaining a powder that is not oxidized. Also, compared with the manufacturing method
5 according to the fourth embodiment, the sifting process can be omitted.

Sixth Embodiment

First, in this embodiment, a concept for forming a dense thick coat by the electric discharge surface treatment is described.

In the conventional electric discharge surface treatment, an
10 electrode material, such as Ti, is chemically reacted in oil through electric discharge to form a hard carbide coat. Therefore, the electrode for electric discharge surface treatment includes a large amount of material easy to form carbide.

Also, as the electric discharge surface treatment proceeds, a
15 material on a surface of a work piece (work) is changed, thereby changing characteristics, such as a thermal conductivity and a melting point, accordingly. For example, when the electric discharge surface treatment is performed on steel, as the electric discharge surface treatment proceeds, the material of the surface of the work piece (work)
20 is changed from steel to TiC, which is ceramic. Accordingly, characteristics, such as the thermal conductivity and the melting point, are changed.

Through experiments performed by the inventors, it has been found that, in such a coat formation process, by adding a material less
25 likely to be carbonized to constituents of the electrode material, a thick

coat can be formed. This is because addition of the material less likely to be carbonized to the electrode increase the amount of materials that remain on the coat remaining to be in the same metal state without becoming a carbide. This has an important significance when forming
5 a thick coat.

Examples of an electrode for electric discharge surface treatment with which formation of a thick coat is possible as described above are listed below. The temperatures in the heating process shown below were obtained through experiments performed by the
10 inventors.

(1) Electrode for electric discharge surface treatment manufactured by compression molding a Co powder and by further performing a heating process

When the Co powder has a grain diameter of the order of 4 μm
15 to 5 μm , the temperature in the heating process after compression molding is preferably 400°C to 600°C. When the Co powder has a grain diameter of the order of 1 μm , the temperature in the heating process after compression molding is preferably 100°C to 300°C. When the Co powder has a grain diameter further smaller than 1 μm ,
20 the temperature in the heating process after compression molding may be 200°C or lower, or in some cases, the heating process is not required.

(2) Electrode for electric discharge surface treatment manufactured by compression molding a powder of an alloy hard to
25 form a carbide, such as Co, and by further performing a heating

process

An electrode for electric discharge surface treatment manufactured by compression molding a Co-based alloy powder (a grain diameter of 1 μm to 3 μm) that includes 25 weight % Cr (chromium), 10 weight % Ni (nickel), 7 weight % W (tungsten), and the like, and by further performing the heating process can also form a dense thick coat. The temperature in the heating process after compression molding is preferably higher than that for the Co powder because of a material difference, of the order of 700°C to 900°C.

While in the above, two examples of the electrode for electric discharge surface treatment have been listed, there are many other examples, since it is found that with any electrode, a thick coat can be formed by the electric discharge surface treatment, as long as certain conditions are satisfied, such that a predetermined amount (for example, 40 weight % or more) of a material hard to be carbonized should be included.

Other than the above, using, for example, Fe (iron) as the electrode material, with an electrode for electric discharge surface treatment formed of a 100% Fe (iron) material, or with an electrode for electric discharge surface treatment formed of a steel material, formation of a thick coat by the electric discharge surface treatment is possible. Also, other than the above, an electrode for electric discharge surface treatment formed of Ni (nickel) or the like allows formation of a thick coat in a electric discharge surface treatment.

Moreover, through experiments conducted by the inventors, it

has been found that, in some cases, even with a material forming a carbide, if the material is finely crushed to be a powder particle of which a grain diameter is 1 μm or less to manufacture an electrode for electric discharge surface treatment, carbonization of the electrode material at the time of the electric discharge surface treatment is suppressed, and it is possible to form a thick coat. Such materials include, for example, Cr (chromium) and Mo (molybdenum).

Through studies performed by the inventors, it has been found that, in the technique of forming a thick coat by the electric discharge surface treatment described above, variations in coat thickness of the coat formed occur in some cases. An Example of such a case is described below.

A Co-based alloy powder (a grain diameter of 1 μm to 3 μm) that includes 25 weight % Cr (chromium), 10 weight % Ni (nickel), 7 weight % W (tungsten), and the like was compression molded, and then the heating process was further performed at a temperature of 800°C to manufacture an electrode for electric discharge surface treatment. Then, the electric discharge surface treatment was performed using this electrode for electric discharge surface treatment to form a coat on a work of an Ni alloy. Specific description is provided below.

First, the electrode for electric discharge surface treatment was manufactured. Fig. 15 is a cross-section of a molder for molding the powder. A lower punch 203 was inserted from a lower portion of a hole formed on a mold (die) 204, and a space formed between the lower punch 203 and the mold (die) 204 was filled with a Co-based alloy

powder 201 including 25 weight % Cr (chromium), 10 weight % Ni (nickel), 7 weight % W (tungsten), and the like.

Then, an upper punch 202 was inserted from an upper portion of the hole formed on the mold (die) 204. Then, the alloy powder 201
5 was compression molded by a pressure applied by a pressurizer or the like from both sides of the molder filled with the powder 201 described above by the upper punch 202 and the lower punch 203. In the following, the alloy powder 201 compression molded is referred to as a green compact. At this time, when a high pressure is applied, the
10 electrode becomes hard, and when a low pressure is applied, the electrode becomes soft. Also, when the grain diameter of the alloy powder 201 of the electrode material is small, the electrode becomes hard, and when the grain diameter of the alloy powder 201 is large, the electrode becomes soft.

15 The green compact is then removed from the molder and heated in a vacuum furnace at a temperature of 800°C, thereby obtaining a conductive compact electrode, that is, the electrode for electric discharge surface treatment.

To improve the transmission of pressure from the press to a
20 portion inside of the alloy powder 201 at the time of compression molding, the alloy powder 201 is mixed with wax, such as paraffin, thereby improving moldability of the alloy powder 201. However, since wax is an insulating material, if a large amount of wax remains in the electrode, the electric resistance of the electrode increases, thereby
25 degrading the electric discharge property.

Therefore, when wax is mixed in the alloy powder 201, it is preferable that wax is removed. Wax can be removed by putting the green compact in the vacuum furnace to be heated. In addition, by heating the green compact, it is possible to decrease the electric resistance of the green compact, and to increase strength of the green compact. Therefore, even when wax is not mixed, heating after compression molding is meaningful.

Next, the electric discharge surface treatment was performed using the electrode for electric discharge surface treatment manufactured in the manner described above to form a coat the work of the Ni alloy. The electric discharge surface treatment performed by an apparatus for electric discharge surface treatment using the electrode for electric discharge surface treatment for the purpose of formation of a thick coat manufactured in the processes described above is shown in Fig. 16. In Fig. 16, a state is shown in which a pulse-like electric discharge occurs.

The apparatus for electric discharge surface treatment shown in Fig. 16 includes an electrode for electric discharge surface treatment 301 (hereinafter, simply "electrode 301"), a dielectric fluid 303 covering an electrode 301 and a work 302 made of the Ni alloy, and a power supply for electric discharge surface treatment 304 that causes a pulse-like electric discharge by applying a voltage between the electrode 301 and the work 302. In Fig. 16, a servo mechanism for controlling an interpole distance, that is, a distance between the electrode 301 and the work 302, a depot storing the dielectric fluid 303,

and the like are omitted because they are not directly related to the present invention.

To form a coat with this apparatus for electric discharge surface treatment, the electrode 301 and the work 302 are placed in the dielectric fluid 303 to be opposed to each other. Then, in the dielectric fluid 303, a pulse-like electric discharge is caused between the electrode 301 and the work 302 by using the power supply for electric discharge surface treatment 304. Specifically, a voltage is applied between the electrode 301 and the work 302 to cause an electric discharge. As shown in Fig. 16, an arc column of electric discharge 305 occurs between the electrode 301 and the work 302.

Then, with the electric discharge energy of the electric discharge occurring between the electrode 301 and the work 302, a coat of the electrode material is formed on a surface of the work, or a coat of a substance resulting from reaction of the electrode material due to the electric discharge energy is formed on the surface of the work. As for polarities, the electrode 301 has a negative polarity, while the work 302 has a positive polarity.

Examples of pulse conditions of the electric discharge for performing the electric discharge surface treatment in the apparatus for electric discharge surface treatment having such a structure as described above are shown in Figs. 17A and 17B. Figs. 17A and 17B are diagrams of examples of pulse conditions of electric discharge in the electric discharge surface treatment, in which Fig. 17A depicts a voltage waveform (waveform of an interpole voltage) between the

electrode 301 and the work 302 at the time of electric discharge, while Fig. 17B depicts a current waveform of a current flowing through the apparatus for electric discharge surface treatment at the time of electric discharge. A voltage value and a current value are each positive in a direction of an arrow shown in each of Figs. 17A and 17B, that is, in an upper direction of a vertical axis. Also, the current value is positive when the electrode 301 side has a negative polarity, while the work 302 is as a positive-polarity electrode.

As shown in Fig. 17A, a no-load voltage u_i is applied between both poles at a time t_0 . A current begins to flow at a time t_1 after an electric-discharge delay time t_d has elapsed, thereby starting the electric discharge. The voltage at this time is an electric-discharge voltage u_e , and the current at this time is represented by a peak current value i_e . Then, when the supply of the voltage between both poles is stopped at a time t_2 , the current stops flowing.

A duration between t_2 to t_1 is referred to as an electric-discharge pulse width t_e . A voltage waveform in a duration between t_0 to t_2 is repeatedly applied between both poles at intervals of a pause time t_o . That is, as shown in Fig. 17A, a pulse-like voltage is applied between the electrode 301 and the work 302.

The pulse conditions used in the present embodiment are such that the peak current value $i_e=10$ A, and the electric-discharge duration (electric discharge pulse width) $t_e=8$ μ s, the pause time $t_o=16$ μ s, and a processing time is 10 minutes. Also, an electrode area (that is, an area to be processed) is equivalent to the area of a circle of which a

diameter is 18 mm.

A dense, thick coat was able to be formed by performing an electric discharge surface treatment with the structure and conditions described above. However, a problem occurred in which, the coat
5 thickness of the coat formed differed every time the process was performed even with the process performed under the same conditions and for the same time duration. Specifically, the amount of deposition (coat thickness) of the coat when a brand-new electrode 301 was used was approximately 150 μm , while the coat thickness of the formed
10 coating when an electrode 301 previously used several days ago was used for performing an electric discharge surface treatment was approximately 100 μm .

If the coat thickness of the formed coating varies even if the process is performed under the same conditions, it is inconvenient in
15 view of automating the process when, for example, coatings are successively formed on the same component. That is, since the coat thickness of the coat cannot be controlled, a coat is formed to be thick, and then a process of removing an excess coating is required. This is disadvantageous in terms of process time and cost.

20 Upon a survey of a cause of such variations in coat thickness of the coat, it has turned out that the cause of variations in coat thickness of the coat is due to an inflow of oil, which is a dielectric fluid used in the electric discharge surface treatment, in the space between the poles. Since the electrode for electric discharge surface treatment is
25 compression molded from a powdered material, its inside is in a state

where many spaces are present. Then, several tens of % of a volume of the electrode is such spaces, and these spaces play an important role in forming a coat by the electric discharge surface treatment.

For example, when too many spaces are present inside the
5 electrode, the strength of the electrode is low. Therefore, the electrode material is not normally supplied by an electric-discharge pulse and a phenomenon occurs such that, upon impact of the electric discharge, the electrode collapses over a wide range. On the other hand, if too few spaces are present, the electrode material is too closely and firmly
10 formed, thereby causing a phenomenon of a short supply of the electrode material by an electric-discharge pulse and making it impossible to form a thick coat.

As such, the spaces in the electrode for electric discharge surface treatment are important in forming a coat. On the other hand,
15 it has been found through experiments performed by the inventors that the spaces in the electrode for electric discharge surface treatment also produce variations in coat thickness of the coat. That is, when the electrode for electric discharge surface treatment is brand-new, the spaces in the electrode are in a hollow state. By contrast, as the
20 number of time for which the electrode is used for the electric discharge surface treatment increases, oil, which is the dielectric fluid, flows into the spaces inside the electrode, and the spaces are filled with oil.

Following effects are caused when the spaces in the electrode for electric discharge surface treatment are filled with the dielectric
25 fluid.

(1) The strength of the electrode is increased because of viscosity of the dielectric fluid in the spaces in the electrode;

(2) An operation of cooling the electrode at the time of the electric discharge surface treatment is enhanced because the dielectric
5 fluid is present in the spaces in the electrode; and

(3) When the dielectric fluid is evaporated after the dielectric fluid enters the spaces in the electrode, only a material having high viscosity, that is, resistant to vaporization, remains in the electrode, thereby increasing the strength of the electrode.

10 With these three effects above, the electrode can be prevented from being excessively consumed due to the electric discharge at the electric discharge surface treatment, thereby making it easy to form a dense coating. On the other hand, however, the above (three) effects mentioned above vary with time, which causes the variations in the coat
15 thickness of the coat. Therefore, the more the electrode is used, that is, the more the electrode is soaked in the dielectric fluid, the thinner the coat becomes even though the electric discharge surface treatment is performed under the same conditions and for the same time duration. Hence, the thickness of the coat decreases.

20 To prevent this, the present embodiment has a feature in which the electrode for electric discharge surface treatment is soaked in a dielectric fluid to fill the spaces in the electrode with the dielectric fluid in advance, thereby suppressing variations in coat thickness of the coat at the time of the electric discharge surface treatment.

25 That is, in a method for manufacturing an electrode for electric

discharge surface treatment according to the present invention, after a powdered material, that is, any one of a metallic powder, a metal compound powder, and a ceramic powder, is compression molded to form a green compact, oil or a dielectric fluid used in the electric

5 discharge surface treatment is caused to flow into the space inside the green compact. The processes up to the process of forming the green compact are similar to those for manufacturing the electrode for electric discharge surface treatment described above.

The electrode for electric discharge surface treatment is

10 manufactured in the manner described above, and the electrode is filled with oil or a dielectric fluid used in the electric discharge surface treatment in the space inside the electrode for electric discharge surface treatment in advance before being used for the electric discharge surface treatment.

15 When the green compact electrode, that is, the electrode for electric discharge surface treatment, is used for forming a coat by the electric discharge surface treatment, the electric discharge surface treatment is performed with the electrode of which the space in the electrode for electric discharge surface treatment is filled with oil or the

20 dielectric solution. Therefore, variations that occur in process between a brand-new electrode and an electrode for which a predetermined time has elapsed since manufactured can also be minimized.

Fig. 18 depicts a state in which a weight of the electrode increases according to a time for soaking the electrode in a dielectric

25 fluid. Amount of increase in weight of the electrode is equivalent to an

amount of the dielectric fluid absorbed in the electrode. From Fig. 18, it can be assumed that the dielectric fluid flows into the space in the electrode within 2 hours to 3 hours.

The present invention is described in more detail below based
5 on a specific embodiment.

A Co-based alloy powder (a grain diameter of 1 μm to 3 μm) that includes Cr (chromium), Ni (nickel), W (tungsten), and the like was compression molded, and then the heating process was further performed at a temperature of 800°C. Thereafter, the electrode having
10 been soaked in the dielectric fluid for 30 hours was used for the electric discharge surface treatment for a work of an Ni alloy. Here, electric-discharge pulse conditions were such that the electrode for use had an electrode area (that is, an area to be processed) of 18 mm, and the peak current value is 10 A, the pulse width is 8 μs , and the pause
15 time is 16 μs , and the process was performed for 10 minutes.

As a result, an amount of deposition (coat thickness) with the use of a brand-new electrode was approximately 100 μm , and the amount when a process was performed 7 days later under the same conditions was also approximately 100 μm . Thus, variations in
20 thickness of the coat were able to be nearly solved.

Results similar to those described above were able to be obtained even with the electrode for electric discharge surface treatment manufactured with a Mo powder and an alloy powder including Mo; an Fe powder and an alloy powder including Fe; and an
25 Ni powder.

According to the sixth embodiment, the compact electrode manufactured, that is, the electrode for electric discharge surface treatment, is soaked in advance in the dielectric fluid used in the electric discharge surface treatment, and then the electric discharge
5 surface treatment is performed with the green compact electrode of which the spaces inside are filled with the dielectric fluid. Therefore, the variations that occur in the process between a brand-new electrode and even an electrode produced after a predetermined time has elapsed can also be minimized.

10 Seventh Embodiment

In the sixth embodiment, a stage of manufacturing an electrode was has been described. In the present embodiment, a method of storing the electrode is described.

When the electrode for electric discharge surface treatment
15 (compact electrode) is stored, if the electrode is stored in air, the dielectric fluid in the spaces inside the electrode evaporates. Therefore, to eliminate the variations in coat formed by the electric discharge surface treatment, it is preferable that the electrode is stored in oil similar to the dielectric liquid. Flow of the dielectric fluid into the
20 electrode is completed in several hours. However, if the electrode is stored in air thereafter, constituents prone to evaporation in the dielectric fluid evaporate, while those resistant to evaporation remains in the electrode. This affects binding strength of powder particles of the electrode material, and also affects a condition of the coat to be
25 formed at the time of performing the electric discharge surface

treatment with the electrode. Therefore, it is preferable that the electrode is stored in the dielectric solution.

That is, by storing the electrode in oil similar to the dielectric fluid, it is possible to eliminate in coat variations due to evaporation of the dielectric absorbed in the electrode in the electric discharge surface treatment.

However, because it takes several days to evaporate the dielectric fluid absorbed in the electrode, time for which the electrode is placed in air at each time of actual processing (for the electric discharge surface treatment) does not cause a problem. For example, when the electrode is set in a tool changer for automation, the electrode is not particularly required to be soaked in oil, as long as the electrode is set within a time in which the dielectric fluid absorbed in the electrode does not evaporate, and the electrode may be left in air.

According to the seventh embodiment, the electrode for electric discharge surface treatment is stored in oil, thereby preventing not only variations in the hardness of the electrode with time, but also oxidation of the electrode material. If the electrode includes an electrode material likely to be oxidized, when the electrode is stored in air for a long time, oxidation of the electrode material proceeds to affect a quality of the electrode and a quality of the coat to be formed.

Therefore, by storing the electrode in oil, it is possible prevent the oxidation of the electrode material, and to stabilize the quality of the electrode and the quality of the coat formed by the electric discharge surface treatment using the electrode.

Eighth Embodiment

In the seventh embodiment described above, the influence upon the formation of the coat of the dielectric absorbed in the electrode has been mentioned. As described above, soaking the electrode in the dielectric fluid is effective in preventing the oxidation of the electrode material.

As oxidation of the electrode material proceeds, the powder material of the electrode changes into ceramics, thereby making it difficult to form a dense coat. In addition to the method of soaking the electrode in the dielectric fluid, to prevent the oxidation of the electrode material, it is also effective to store the electrode in a vacuum package or in an inert gas (a noble gas), such as helium or argon, or an inert gas, such as nitrogen. However, in these cases, although the effect of preventing oxidation of the material can be achieved, the effect obtainable by the dielectric fluid sufficiently absorbed in the electrode cannot be achieved.

According to the eighth embodiment, the electrode for electric discharge surface treatment is stored in vacuum or an inert gas, thereby preventing oxidation of the powder material of the electrode. As a result, even an electrode in which a long time has elapsed since manufactured can form a dense coat.

As described, according to the present invention, it is possible to manufacture an electrode for electric discharge surface treatment with which surface treatment in which a stable electric discharge is generated, and in which a thick coat can be formed without

deteriorating surface roughness.

Moreover, according to the present invention, it is possible to manufacture an electrode with a metallic powder likely to be oxidized without making the metallic powder oxidized during a manufacturing
5 process, and is possible to form a thick metallic coat by electric discharge surface treatment.

Furthermore, according to the present invention, it is possible to form a coat without variation by the electric discharge surface treatment by using the electrode for electric discharge surface treatment.

10

INDUSTRIAL APPLICABILITY

As described, the electrode for electric discharge surface treatment is suitable in industries related to surface treatment for forming a coat on a surface of a work piece, and particularly suitable for
15 industries related to surface treatment for forming a thick coat on a surface of a work piece.

CLAIMS

1. An electrode for electric discharge surface treatment, the electrode being a green compact that is formed by compression molding a material powder that is any one of a metallic powder, a metallic compound powder, and a conductive ceramic powder, the electrode used for electric discharge surface treatment in which a pulse-like electric discharge is caused between the electrode and a work in a dielectric fluid or an atmosphere, and in which a coat of an electrode material or a substance that is generated by a reaction of the electrode material due to an electric discharge energy is formed on a surface of the work, wherein

a powder solid that is formed as a result of coagulation of a mixture of the material powder and a wax or a solvent has a diameter shorter than a distance between the electrode and the work, the powder solid included in the green compact, wherein

the diameter of the powder solid is 0.3 millimeters (mm) or less.

2. The electrode according to claim 1 or 2, wherein

an average grain diameter of the material powder is 3 micrometers (μm) or less.

3. The electrode according to any one of claim 1 to 2, wherein

the metallic compound powder is a cobalt alloy powder.

4. The electrode according to claim 3, wherein

the cobalt alloy powder is a stellite powder.

5. The electrode according to Claim 1, wherein

the electrode is formed by finely crushing the material powder in a liquid that volatilizes in an atmosphere, and then by compression molding the material powder crushed in a state in which the material power is not completely dried.

6. The electrode according to Claim 1, wherein

the electrode is formed by compression molding the material powder that is finely crushed in a liquid that volatilizes in an atmosphere while drying the material

powder, which is crushed, under pressure.

7. The electrode according to Claim 1, wherein
the electrode is formed by compression molding the material powder that is finely crushed in a liquid, and then dried in an atmosphere of which an amount of oxygen is controlled, the material powder dried in such a manner that only a surface of the material powder is oxidized.
8. The electrode according to any one of claims 5 to 7, wherein
the material powder is any one of a powder of metal that is likely to be oxidized in an atmosphere and a powder of an alloy of which a base material is metal that is likely to be oxidized.
9. The electrode according to claim 8, wherein
the metal that is likely to be oxidized is any one or a combination of chromium, titanium, and aluminum.
10. The electrode according to Claim 1, wherein
the electrode is formed by compression molding the material powder that is finely crushed in wax.
11. The electrode according to Claim 1, wherein
any one of oil and the dielectric fluid is soaked in an internal space of the green compact.
12. The electrode according to Claim 1, wherein
the green compact is heated, and
any one of oil and the dielectric fluid is soaked in an internal space of the green compact heated.
13. The electrode according to claim 11 or 12, wherein
an average grain diameter of the metallic powder and the metallic compound powder is 3 μm or less.

14. The electrode according to any one of claims 11 to 13, wherein
the metallic powder and the metallic compound powder includes a cobalt powder and a cobalt-based alloy, the cobalt-based alloy including any one of chromium, nickel, and tungsten.
15. The electrode according to any one of claims 11 to 14, wherein
the electrode material includes a material less likely to be carbonized for 40 volume % or more.
16. A method for manufacturing an electrode for electric discharge surface treatment, the electrode being a green compact that is formed by compression molding a material powder that is any one of a metallic powder, a metallic compound powder, and a conductive ceramic powder, the electrode used for electric discharge surface treatment in which a pulse-like electric discharge is caused between the electrode and a work in a dielectric fluid or an atmosphere, and in which a coat of an electrode material or a substance that is generated by a reaction of the electrode material due to an electric discharge energy is formed on a surface of the work, the method comprising:
 - sorting a powder solid that is formed as a result of coagulation of the material powder;
 - fragmenting the powder solid; and
 - compression molding the material powder of which the powder solid is sorted or fragmented, wherein
 - the powder solid is sorted and fragmented in such a manner that a diameter of the powder solid included in the green compact is shorter than a distance between the electrode and the work, wherein
 - the powder solid is formed as a result of coagulation of a mixture of the material powder and a wax or a solvent, wherein
 - the diameter of the powder solid is 0.3 millimeters (mm) or less.
17. The method according to claim 16, wherein
the sorting includes sorting the powder solid with a sifter having a

predetermined mesh width.

18. The method according to claim 17, wherein
the predetermined mesh width is 0.3 mm or less.
19. The method according to any one of claims 16 to 18, further comprising
crushing the material powder, wherein
the crushing is performed before the sorting and the fragmenting.
20. The method according to claim 19, wherein
the crushing includes crushing the material powder in such a manner that an
average grain diameter of the material powder is 3 μm or less.
21. The method according to claim 19 or 20, wherein
the crushing includes crushing the material powder with a mill apparatus.
22. The method according to any one of claims 19 to 21, further comprising:
drying the material powder crushed; and
sifting the material powder dried, wherein
the crushing includes crushing the material powder in a solution.
23. The method according to any one of claims 16 to 23, further comprising:
mixing the material powder sorted or fragmented with wax; and
sifting the material powder mixed with wax, wherein
the mixing and the sifting are performed after the sorting and the fragmenting,
and before the compression molding.