

DESCRIPTION

IRON-BASED PART AND IRON-BASED PART PRODUCTION METHOD

Technical Field

The present invention relates to an iron-based part made of iron or iron-based alloy. The part is used as a mechanical element or a mechanism part of various types. The present invention also relates to a manufacturing method for the iron-based part. More specifically, the present invention relates to a surface modification technique for appropriately adjusting not only a sliding performance and a corrosion resistance of an iron-based part, but also a hardness of the iron-based part near its surface.

Background Art

A mechanical element such as a gear, a cam, or a link arm made of iron or iron-based alloy or a mechanism element such as a camera, office equipment, transport equipment, or a water treatment device can be manufactured by selecting a composition from among various compositions ranging from a composition near to pure iron to a composition containing an element other than iron such as carbon, and using a material made of a wrought metal (hereinafter, “wrought material”). The mechanical element or the mechanism element can also be manufactured by forming and sintering a mixture of metal powders or other additive powders (hereinafter, “sintered material”).

If the mechanical element is manufactured using a wrought

material, the mechanical element is formed into a desired shape by an arbitrary means of forming such as plastic forming, shearing, or machining. If the mechanical element is manufactured using the sintered material, the material is formed into the intended shape by powder forming using a die. If either material is used to manufacture the mechanical element, a modification treatment such as carburizing, nitriding, quenching and tempering, or plating is performed according to properties required of the mechanical element.

Particularly if the mechanical element is required to have corrosion resistance or the like and is to be manufactured using each formation method, a corrosion-resistant iron-based alloy such as a stainless steel is used, or a surface of a material having a relatively low corrosion resistance such as structural carbon steel is plated with nickel.

Various proposals have been conventionally made for techniques for manufacturing a mechanical element required to have excellent corrosion resistance or the like by plating an alloy surface with nickel. For example, there is proposed a manufacturing technique including subjecting alloy steel to electroless nickel plating, subjecting a plated member to a heat treatment at a temperature of 300 to 400°C to transform phosphorus contained in the nickel plated layer into nickel tri-phosphide (Ni_3P) and to make a hardness of the nickel plated alloy steel about Hv800 to 900, and providing good performance to other members to the nickel plated surface (see Japanese Patent Application Laid-Open No. 6-313434, pages 2 and 3). There is also proposed a

manufacturing technique for obtaining a steel plate which is excellent in corrosion resistance by subjecting a steel plate to nickel plating and to a heat treatment at a temperature of 600 to 850°C for 10 to 120 seconds, thereby transforming part of a plated layer into a nickel-iron alloy phase (see Japanese Patent Application Laid-Open No. 11-61484, page 4).

The conventional techniques disclosed by these two Patent Documents have, however, the following disadvantages. The mechanical elements or the like disclosed therein are excellent in corrosion resistance and performance. However, no special treatment, such as a treatment for ensuring a smooth change in hardness from the alloy steel to the nickel plated layer, in relation to the change in hardness from the plated surface toward a deep portion of the plated member is performed. Due to this, the nickel plated member is easily peeled off from the alloy steel. Under these circumstances, therefore, demand for developing a technique for manufacturing an iron-based part by appropriately adjusting not only the required properties stated above, but also the hardness of the member from the plated surface to an interior of the plated member in a depth direction, is now increasing.

Disclosure of the Invention

The present invention has been achieved in light of these requirements. It is, therefore, an object of the present invention to provide an iron-based part having not only an excellent sliding performance and an excellent corrosion resistance but also a hardness which is appropriately adjusted from a plated surface to

an interior of a plated member.

According to one aspect of the present invention, there is provided an iron-based part in which a surface of a base metal made of iron or iron-based alloy is covered with a nickel layer that contains carbon or a nickel layer that contains carbon and phosphorus, a nickel diffused layer, the nickel content of which decreases in a depth direction, is formed on the base metal made of the iron or iron-based alloy, and at least a surface layer of the nickel diffused layer contains the carbon.

In the iron-based part according to the present invention, a surface of iron or iron-based alloy (hereinafter, "base metal") is covered with a nickel layer. Therefore, the iron-based part can realize the properties required in the techniques disclosed by the two Patent Documents, i.e., the excellent sliding performance and the excellent corrosion resistance.

In order to realize these required properties, a nickel diffused layer, a nickel content of which decreases in a depth direction of the base metal, is formed in the base metal of the iron-based part according to the present invention, and the nickel layer and the base metal are joined to each other by diffusion. It is, therefore, possible to prevent the nickel layer from being peeled off from the base metal.

Further, in the iron-based part according to the present invention, the nickel layer contains either carbon or both carbon and phosphorus. Therefore, a hardness and a strength of the nickel layer can be sufficiently increased, and the iron-based part possesses both the sliding performance and the corrosion resistance

because of the presence of the nickel layer.

In such an iron-based part, the nickel diffused layer can have a quenched metal structure including martensite. In addition, since the surface of the base metal is covered with the nickel layer, the iron-based part is preferably applied to a mechanical element or a mechanism element required to have the abrasion resistance or the corrosion resistance. The iron-based part can be manufactured using the base metal made of a wrought material or the base metal made of a sintered material.

The inventors of the present invention found the following information (1) to (5) for a production method for the iron-based part according to the present invention.

(1) If the base metal plated with nickel and made of an iron-based material having a low carbon content is heated under a carburizing gas atmosphere, then carbon is mixed into the nickel layer and solid-solution treated, and the hardness of the nickel layer is increased. The carbon passes through the nickel layer and enters the member. The amount of the carbon that reaches the base metal is highest at the surface of the nickel layer, and gradually decreases toward the interior of the member.

(2) If the base metal plated with nickel and made of the iron-based material that contains carbon is heated under a gas atmosphere having a carbon potential lower than the carbon content of the base metal, then the carbon contained in the base metal is mixed into the nickel layer and solid-solution treated, and the hardness of the nickel layer is increased.

(3) The heating of the iron-based material to an austenite region

temperature under the carburizing gas atmosphere promotes carburizing if the temperature is higher. If the gas atmosphere is constant, the carburizing amount can be controlled by the heating temperature and the heating duration.

(4) If the base metal plated with nickel and made of the iron-based material is heated to the austenite region temperature of the iron-based metal, nickel and iron are mutually diffused and alloyed. The nickel content gradually decreases from the nickel layer toward a deep portion of the base metal. The diffusion of nickel enables formation of a state in which the nickel layer is metallurgically strongly coupled with the surface of the base metal. Due to this, even if quenching, plastic forming, barrel finishing, or the like is conducted on the iron-based part, the nickel layer is not peeled off from the base metal. Pits of the nickel layer are reduced or removed, thus providing a satisfactory layer. It is noted that the mutual diffusion of nickel and iron is promoted if the gas carburizing accompanies the above-stated treatment.

(5) The phosphorus contained in the electroless nickel plated layer intensifies the hardness of the nickel layer. In addition, the phosphorus contained in the electroless nickel plated layer functions to inhibit carburizing of the base metal, carburizing the nickel layer using the carbon contained in the base metal, and carbon migration. Thus, the carbon content of the heat-treated base metal can be adjusted according to the phosphorus content of the electroless nickel-plated layer.

That is, according to another aspect of the present invention, there is provided a production method for an iron-based part having

the steps of: covering a surface of a base metal made of iron or iron-based alloy that contains carbon with a nickel layer; heating the base metal to an austenite region temperature in an iron-carbon standard constitutional diagram under a carburizing gas atmosphere for the base metal made of iron or under one of a gas atmosphere having a carbon potential of 0.1 to 1.2% for the base metal made of the iron-based alloy containing the carbon, a gas atmosphere having a carbon potential in equilibrium with the carbon content of the iron-based alloy, and a gas atmosphere having a carbon potential lower than the carbon content of the base metal; and cooling the base metal.

The production method for the iron-based sintered part according to the present invention can realize excellent sliding performance and excellent corrosion resistance of the iron-based part by the above-described method. Based on this method, in the iron-based part, it is particularly possible to prevent the nickel layer from being peeled off from the base metal, to provide excellent sliding performance, abrasion resistance, and corrosion resistance to the nickel layer, and to increase the hardness and the strength of the nickel layer.

According to yet another aspect of the present invention, there is provided a production method for an iron-based part having steps of: covering a surface of an iron base metal or an iron-based alloy base metal with a nickel layer; heating the base metal to an austenite region temperature in an iron-carbon standard constitutional diagram; and quenching and tempering the base metal.

By carrying out the quenching and tempering, the base metal can be hardened at the part covered with the nickel layer, the structure and mechanical properties of the part can be stabilized, the toughness of the part can be restored, and residual stress in the part can be reduced.

A concrete means for the quenching includes carburizing and quenching. If the carburizing and quenching is performed, it is preferable that heating of the base metal to the austenite region temperature be performed first at a first temperature for promoting carburizing and nickel diffusion, and then be performed at a second temperature lower than the first temperature, and the quenching is performed. That is, the carburizing is promoted at the temperature (the first temperature) higher by about 100°C than an A_3 transformation point of the iron-based material, and then the quenching is performed while the temperature is maintained at the temperature (the second temperature) higher by about 50°C than the A_3 transformation point, whereby the part which has a relatively large carburizing quantity and to which residual austenite by the quenching occurs less can be obtained.

In the production method according to the present invention, the nickel layer can be laminated by performing one of nickel electroplating and electroless nickel plating, or by both performing. If the nickel layer is a nickel-phosphorus plated layer formed by the electroless nickel plating and having a phosphorus content of 15 mass % or less, in particular, it is preferable that the phosphorus content be reduced so as to increase the carburizing quantity of the iron or iron-based alloy and that the phosphorus content is

increased so as to reduce the carburizing quantity of the iron or iron-based alloy. The phosphorus content of the nickel plated layer formed by the electroless nickel plating can be adjusted based on the content and the pH of sodium phosphate contained in a plating solution. If the nickel plated layer is heated, a eutectic structure of nickel tri-phosphide (Ni_3P) is precipitated from an amorphous structure, thereby hardening the plated layer. Therefore, if the phosphorus content is higher, the hardness of the nickel layer can be increased. It is noted that Ni_3P can be examined by X-ray diffractometry (“XRD”).

Further, the phosphorus contained in the nickel layer can inhibit carburizing by causing the appearance of the eutectic structure. If the phosphorus content of the nickel layer exceeds 15 mass %, it is difficult to carburize the nickel layer and the iron-based metal. Thus, the adjustment of the carburizing of the base metal can be made by adjusting the phosphorus content as well as the carbon potential of the gas atmosphere and the heating temperature. In addition, if the base metal made of the iron-based alloy containing carbon is heated under the gas atmosphere having the carbon potential lower than the carbon content of the base metal, the phosphorus contained in the nickel layer can inhibit carburizing of the nickel layer. Therefore, by adjusting the phosphorus content of the electroless nickel plated layer, the carbon content of the heat-treated base metal can be adjusted.

The iron-based part used for the iron-based part production method can be manufactured using a base metal made of a wrought material or using a base metal made of a sintered material.

According to the present invention, the nickel plated layer is formed on the surface of the base metal, the base metal is heated to the austenite region temperature to cause migration of the carbon contained in the gas atmosphere or that contained in the base metal between the base metal and the nickel layer, and the base metal is gradually cooled or quenched. It is thereby possible to cover the surface of the base metal with the nickel layer that contains carbon, and to strongly couple the nickel layer with the iron-based base metal. Hence, the present invention is promising in that it can provide a mechanical element or a mechanism element capable of applying the corrosion resistance to the surface of a base metal irrespective of whether the base metal is made of iron that does not contain carbon or iron-based alloy that contains carbon, or to the surface of the base metal made of even a relatively inexpensive iron-based material, capable of realizing excellent sliding performance to a counterpart member, and capable of exhibiting properties that a surface layer portion is hard and that an internal portion has high toughness.

Brief Description of the Drawings

Fig. 1 is a graph which shows a depth of a heat-treated compact subjected to nickel plating (a first example) from a surface and densities of respective elements as measured by count number;

Fig. 2 is a graph which shows a depth of a heat-treated compact subjected to nickel plating (a third example) from a surface and densities of respective elements as measured by count number; and

Figs. 3A and 3B are respectively a photograph of an outside of a sample in the first example, and a photograph of an outside of a sample which is subjected only to the nickel plating, after salt spray tests.

Best Mode for Carrying out the Invention

An embodiment of the present invention will be described hereinafter.

(1) Base Metal Made of Iron or Iron-Based Alloy

As a base metal made of iron or iron-based alloy which is to be plated, both a wrought material and a sintered material are available. As the wrought material, low carbon steel or an alloy of various types having a low carbon content such as structural carbon steel can be used. The base metal made of the wrought material is formed by an ordinary method such as plastic forming, blanking, machining, or grinding, and a post treatment such as barrel finishing or shot peening can be conducted on the base metal if it is necessary to do so.

As the sintered material, pure iron containing no additive elements, alloys such as Fe-Cu alloy and Fe-Cu-C alloy, and sintered alloy containing such elements as Ni, Cr, Mo and V for use when a high mechanical strength is required are available. A density of the sintered material can be set at about 6.5 Mg/m^3 . Preferably, the sintered material having a high density and including fewer pores is used since it is possible to make it difficult for a plating solution to enter the pores. If the sintered material having high density and fewer pores is used, a post treatment such

as machining, barrel finishing, or shot peening can be conducted on the sintered compact.

(2) Electroplating

Conventional electroplating is used. A plating process is generally realized by sequentially carrying out an alkali immersion degreasing treatment, an electrolytic cleaning treatment, an acid activation treatment, a ground layer nickel plating treatment, and a nickel plating treatment on the base metal made of iron or iron-based alloy. A treatment solution and a treatment time for each treatment step are as follows.

The alkali immersion degreasing treatment is performed by immersing the base metal in a warm aqueous solution containing sodium hydroxide, sodium silicate, sodium phosphate, and sodium carbonate for about 10 minutes. The electrolytic cleaning treatment is performed by applying current at a current density of 10 A/dm^2 in a warm aqueous solution containing sodium hydroxide, sodium silicate, and sodium carbonate, and immersing the base metal in the solution for 10 minutes. The acid activation treatment is performed by immersing the base metal in a hydrochloric acid solution for about 1 minute. The ground layer nickel plating treatment is performed by applying current at a current density of 5 to 10 A/dm^2 in an aqueous solution containing nickel sulfate, nickel chloride and hydrochloric acid, and immersing a base metal in the solution for about 15 minutes. The nickel plating treatment is performed by applying current at a current density of 5 A/dm^2 in an aqueous solution containing nickel sulfate, nickel chloride and boric acid, and by immersing the base

metal in the solution for about 12 minutes.

(3) Electroless Plating

Conventional electroless plating is used. A plating process is generally realized by sequentially carrying out an alkali immersion degreasing treatment, an acid activation treatment, and an electroless nickel plating on the base metal made of iron or iron-based alloy. A treatment solution and a treatment time for each treatment step are as follows.

The alkali immersion degreasing treatment is performed by immersing the base metal in a warm aqueous solution containing sodium hydroxide, sodium silicate, sodium phosphate, and sodium carbonate for about 10 minutes. The acid activation treatment is performed by immersing the base metal in a hydrochloric acid solution for about 1 minute. The electroless nickel plating treatment is performed by immersing the base metal in a warm aqueous solution containing sodium hyposulfite, sodium citrate, sodium acetate, and nickel chloride for about 25 minutes. This electroless nickel plating can instead be performed by nickel-phosphorus electroplating. In the latter case, a phosphorus content can be adjusted based on the content and the pH of sodium phosphate contained in the plating solution.

(4) Thickness of Nickel Plated Layer

A thickness of a nickel plated layer can be appropriately set according to a dimensional accuracy, a corrosion resistance, and the like of a product. The thickness is normally set at about 2 to 8 micrometers. The thickness of the nickel plated layer can be controlled by the duration the base metal is immersed in the plating

solution. The nickel plated layer can be a plurality of nickel plated laminated layers by performing at least one of the nickel plating and the electroless nickel plating.

(5) Heat Treatment

As a heat treatment, both a heat treatment for heating the base metal to a temperature of an austenite region of the iron-based material and for gradually cooling the base metal, and a heat treatment for carrying out quenching and tempering to the base metal are possible. The former is effective if a soft part is obtained in anticipation of a nickel diffusion effect of diffusing nickel into the base metal. The latter is appropriate if a harder part is obtained in anticipation of this nickel diffusion effect.

As a gas atmosphere, a temperature, a heating time, and the like of the heat treatment, normal processing conditions can be adopted.

The gas atmosphere of the heat treatment is as follows. A base metal that does not contain carbon is heated under a carburizing gas atmosphere. The base metal that contains carbon of 0.6 mass % or less can be similarly heated under the carburizing gas atmosphere. A carbon potential of the carburizing gas atmosphere is determined according to the carbon content of the base metal. For example, if the base metal is an iron-based alloy having a carbon content of about 0.2 mass %, the carbon potential is set at about 0.6 to 0.8%. If so, the heat treatment temperature is set at about 850 to 900°C equal to or higher than an A_3 transformation point, and the heating time is set at about 90 to 180 minutes. If a carburizing depth of the base metal is intended to be

small, the carbon potential can be set high, up to about 1.2%. By thus carrying out the heat treatment, the nickel layer and the base metal located deep inside the nickel layer are carburized, and nickel and iron are alternately diffused into the base metal and the nickel layer, respectively. Further, nickel and carbon contents are gradually reduced from a surface toward a deep portion.

If quenching is performed after the carburizing heat treatment, a carburizing temperature can be set relatively high, e.g., a temperature higher by about 100°C than the A_3 transformation point, and a holding temperature at a quenching preparation stage can be set higher by about 50°C than the A_3 transformation point. By carrying out the heat treatment in two stages, carburizing time can be reduced and a good quenched structure can be obtained. The tempering is performed by heating the base metal to a temperature of about 180°C for about 1 hour in an ordinary manner, and by cooling the base metal afterwards.

The heat treatment can be performed on the base metal that contains carbon under the gas atmosphere having a carbon potential set equal to the carbon content of the base metal. By carrying out the heat treatment under the gas atmosphere at an equilibrium carbon concentration, a nickel plated layer is carburized using the carbon contained in the gas atmosphere and the base metal, the nickel layer and the iron-based material are substantially equal in carbon content, and nickel is diffused into the base metal. The base metal to be used herein preferably has a carbon content of about 0.4 to 0.6 mass %.

The heat treatment can be performed on the base metal that

has a relatively high carbon content under the gas atmosphere having a lower carbon potential than the carbon content of the base metal. In this case, the carbon metal having a carbon content of, for example, about 0.4 to 0.9 mass % can be used. If the heat treatment is performed under the gas atmosphere having the lower carbon potential than the carbon content of the base metal, the carbon contained in the gas atmosphere and that contained in the base metal are mixed into the nickel layer (the nickel layer is carburized using the carbon contained in the gas atmosphere and that contained in the base metal). The carbon content of a surface layer portion of the base metal is reduced and nickel is diffused into the surface layer portion. If the heat treatment is performed in the gas atmosphere having no carbon potential, then the nickel plated layer is carburized using only the carbon contained in the base metal, the carbon content of the base metal is reduced, and the content of a surface of the nickel plated layer is low. The carbon potential of the gas atmosphere is, therefore, preferably set at 0.1% or more. As can be seen, the nickel layer and the base metal are firmly coupled to each other by the mutual diffusion of nickel and iron. Therefore, peeling hardly occurs even if shearing is performed or an impact is applied. In addition, cracking and peeling hardly occur even if quenching is performed.

(6) Cross-Sectional Structure of Product

A surface of a product obtained by heating and then gradually cooling the nickel plated base metal under the carburizing gas atmosphere is covered with the nickel layer, and a layer below the nickel layer has an iron pearlite structure or a

mixture structure of ferrite and pearlite. If the base metal does not contain carbon before the heat treatment and a volume of the base metal is high, a central portion of the base metal often has a pearlite structure. A gradually cooled product obtained using the base metal that contains carbon before the heat treatment has an iron pearlite structure or a mixed structure of ferrite and pearlite. A product obtained using the base metal made of the sintered material is in a state in which a surface of the product is sealed by the nickel layer. In a product obtained by heating the nickel plated base metal that is made of iron or iron-based alloy, and quenching and tempering the base metal afterwards, a region which contains carbon and into which nickel and iron are diffused has an improved hardenability. Therefore, the surface layer portion of the base metal, in particular, is in a state in which the portion tends to be transformed into a martensite structure by rapid cooling. The nickel content of the base metal is reduced from the surface layer to the deep portion of the base metal. Therefore, even if the surface layer portion of the base metal has the martensite structure, the deep portion of the base metal often has a troostite structure or a bainite structure. If the base metal that contains no carbon and that is relatively large is used, the central portion of the base metal has a ferrite structure.

A product obtained by heating and then gradually cooling the nickel plated base metal that contains carbon under a gas atmosphere having a carbon potential equal to the carbon content of the base metal has a pearlite structure or a mixture structure of ferrite and pearlite. In addition, a product obtained by heating and

then gradually cooling the base metal that contains carbon under a gas atmosphere having a carbon potential lower than the carbon content of the base metal has similarly a pearlite structure or a mixture structure of ferrite and pearlite. The hardenability of a region in which nickel is diffused into an iron matrix is improved. Therefore, if the cooling rate is relatively high, the product has a bainite structure or a fine pearlite structure.

A cross section of such a product can be subjected to an analysis of carbon, nickel, phosphorus, and iron concentrations (indicated by number of detected counts, which similarly applies hereafter) using an electron probe microanalyzer (“EPMA”). For example, concentrations of respective elements as a result of analyzing the cross section of the product obtained by heating and gradually cooling the nickel plated base metal under the carburizing gas atmosphere are as follows. The carbon concentration is highest on the surface of the nickel layer, and decreases toward the interior thereof. The nickel concentration is low at the surface of the nickel layer since much carbon is contained in the deep portion of the nickel layer. In addition, as a result of a decrease in the carbon content toward the deep portion of the nickel layer, the nickel concentration is the highest in a slightly deep portion from the surface of the nickel layer, and decreases toward the deeper portion by the diffusion of nickel into the iron matrix. On the other hand, for the product obtained by heating and cooling the base metal that contains carbon under the gas atmosphere having a low carbon potential, the carbon concentration is lower in the nickel diffused layer than the deep

portion and is lowest on the surface of the nickel layer. This is because carbon contained in the base metal is mixed into the nickel layer.

Phosphorus concentration follows a similar pattern to that of the nickel concentration. That is, the phosphorus concentration is low at the surface of the nickel layer and is highest following a decrease in the carbon concentration toward the slightly deep portion. In addition, the phosphorus concentration decreases toward a deep region in which iron and nickel are mutually diffused. It is noted that the higher the phosphorus content of the nickel-phosphorus plated layer, the lower the carbon concentration and the smaller the depth of carbon diffusion from the surface. The iron concentration is, in contrast, reduced toward the surface of the product by the diffusion of nickel, carbon, or phosphorus.

(7) Outside of Product

The surface of the nickel layer that has been subjected to the heat treatment has a white gray color without gloss. If the heat treatment is performed under the carburizing gas atmosphere having the high carbon potential, soot often adheres to the surface of the nickel layer (the surface of the nickel layer is often sooty). The soot can be removed by barrel finishing or the like. By carrying out the heat treatment, the nickel layer is free of defects such as pits, and is metallurgically coupled with the base metal. If the sintered material having bores is used as the base metal, in particular, the surface of the product is sealed, thereby exhibiting an excellent corrosion resistance. If a salt spray test is conducted on the nickel plated product without the heat treatment and the

nickel product which has been subjected to the heat treatment, the difference between the two products is quite clear.

Examples

The present invention will be specifically described with reference to the following examples.

Heat-treated compact if sintered material is used as base metal

First and Second Examples

A powder obtained by mixing an atomized iron powder ("Atomized Steel Powder 300M" manufactured by Kobe Steel, Ltd.), an electrolytic copper powder ("CE15" manufactured by Fukuda Kinzoku Hakufun Kogyo), a graphite powder (manufactured by Southwester Graphite Company), and a lubricant (zinc stearate) by respective predetermined proportions, is compression-formed in a die, and sintered under a butane denatured gas atmosphere at 1120°C. The composition of the sintered compact is such that a copper content is 1.5 mass % and a combined carbon content is 0.2 mass %, and a density is 6.7 Mg/m³.

The sintered compact is subjected to nickel electroplating (a first example). The sintered compact is subjected to electroless nickel plating (a second example). The thickness of the nickel plated layer is 5 micrometers in each of the first example and the second example. The phosphorus content of the electroless nickel plated layer is set to be low. Under these conditions, samples in the first and the second examples are each sequentially subjected to quenching and tempering. The quenching is performed by heating

each sample under a carburizing gas atmosphere having a carbon potential of 0.8% at 850°C for 2 hours, and then oil quenching the heated sample. The tempering is performed by heating and then gradually cooling the sample in atmospheric air at 180°C for 1 hour.

Third and Fourth Examples

The base metal is manufactured using the same material powders and the same production method as those in the first and the second examples except that the combined carbon content of the sintered compact is 0.6 mass %. The sintered compact is subjected to nickel electroplating (a third example). The sintered compact is subjected to electroless nickel plating (a fourth example). Samples in the first and the second examples are heated under a gas atmosphere having a carbon potential of 0.1% at 880°C for 1 hour, and were then subjected to quenching and tempering.

Fifth Example

The base metal is manufactured by the same production method as that in the third and the fourth examples, with the combined carbon content of the sintered compact set at 0.6 mass %. This sintered compact is subjected to nickel electroplating, heated under a gas atmosphere having a carbon potential of 0.6% at 850°C for 2 hours, and then subjected to quenching and tempering in a manner similar to that of the third and the fourth examples.

Cross-sectional hardnesses of the respective samples in the first to the fifth examples are illustrated in Table 1 below.

Table 1

CROSS-SECTIONAL HARDNESS OF HEAT-TREATED SAMPLE
(MHV)

DISTANCE FROM SURFACE(mm)	0.1	0.3	0.5	1
FIRST EXAMPLE	770	765	730	675
SECOND EXAMPLE	765	725	700	655
THIRD EXAMPLE	580	600	630	660
FOURTH EXAMPLE	600	620	640	665
FIFTH EXAMPLE	740	725	700	670

According to Table 1, in each of the first and the second examples, the surface layer portion of the base metal has a structure including martensite. This is because nickel is diffused into the base metal and the nickel plated layer is carburized. As compared with the samples subjected to electroplating, the samples subjected to electroless nickel plating are slightly low in hardness in both the surface layer portion and the deep portion. This is because the phosphorus contained in the electroless nickel plated layer inhibits carburizing of the nickel plated layer. In the third and the fourth examples, in contrast, hardnesses of the surface layer portions of the base metals are low. This is because the carbon potential of the gas atmosphere for the heat treatment is low and the carbon content of the base metal accordingly reduced during heating. Further, as compared with the sample subjected to nickel electroplating (the third example), the sample subjected to electroless nickel plating (the fourth example) is slightly higher in hardness. This is because phosphorus contained in the electroless nickel plated layer inhibits movement of carbon contained in the base metal. In the fifth example, the surface layer portion of the

base metal has structure including martensite. This is because nickel is diffused into the base metal and the base metal made of iron-based sintered alloy has a high carbon content.

Fig. 1 depicts a result of linearly analyzing a cross section of the heat-treated sample in the first example (the base material having the carbon content of 0.2%, the electroplating, the heat treatment under the gas atmosphere having the carbon potential of 0.8%) using the EPMA. In the graph of Fig. 1, the vertical axis indicates a concentration (number of detected counts) of each element and the horizontal axis indicates a depth from the surface. As can be seen from Fig. 1, nickel and iron are mutually diffused, and the nickel layer and the nickel-carbon diffused layer are both carburized. Fig. 2 depicts a result of linearly analyzing a cross section of the heat-treated sample in the third example (the base material having the carbon content of 0.6%, the electroplating, the heat treatment under the gas atmosphere having the carbon potential of 0.1%) using the EPMA. As can be seen from Fig. 2, the diffusion of nickel into the base metal is slightly lower, and the carbon contained in the base metal is diffused into the nickel layer. In addition, the carbon concentration on the surface of the nickel layer is low. These facts indicate that if the base metal is heated under the carburizing gas atmosphere during quenching as in the first example, the mutual diffusion of nickel and iron is promoted.

As for the heat-treated sample in the second example (the base material having the carbon content of 0.2%, the electroless plating, the heat treatment under the gas atmosphere having the carbon potential of 0.8%), although not shown in the figures, iron,

nickel, and carbon have the same patterns as those shown in Fig. 1. The heat-treated sample in the second example differs from that in the first example in that the carbon concentration is slightly low even in the surface portion, and the carburizing depth is slightly smaller. This is because phosphorus inhibits carburizing of the nickel layer. In the second example, the phosphorus concentration is low in the surface portion similarly to the nickel concentration indicated by the nickel pattern, and is highest at a distance of about 4 micrometers from the surface. Further, phosphorus reduced from the highest point in a depth direction, and is diffused at a distance of about 10 micrometers from the surface. As for the heat-treated sample in the fourth example (the base material having a carbon content of 0.6%, the electroplating, the heat treatment under the gas atmosphere having the carbon potential of 0.1%), although not shown in the figures, iron, nickel, and carbon have similar patterns to those shown in Fig. 2. The heat-treated sample in the fifth example differs from that in the first example in that the surface of the nickel layer and the base metal are substantially equal in carbon concentration. This is because the nickel layer is carburized using the carbon contained in the gas atmosphere for the heat treatment and that contained in the base metal. The diffusion of nickel into the base metal is slightly low.

Figs. 3A and 3B are photographs of the outsides of samples after salt spray tests were conducted thereon for 96 hours. Fig. 3A is a photograph of the outside of the sample in the first embodiment, and Fig. 3B is a photograph of the outside of the sample which is subjected to nickel electroplating but which is not subjected to the

heat treatment. As for the sample in the first example, defects of the nickel layer are removed while the nickel layer is sintered by heating and carburizing in the heat treatment. In addition, the nickel plated layer is believed to be stronger by the diffusion of nickel and iron. As for the sample subjected to the nickel electroplating but not subjected to the heat treatment, brown rust formed in large quantities. Although covered with the nickel plated layer, the sample is considered to include fine clearances. Although not shown in the figures, as for the samples in the second to the fifth examples, rust formed in small quantities, similarly to the sample in the first example. Therefore, no difference is discerned between the first example and the other examples. This is because the nickel is diffused into the base metal, the nickel plated layer is reliably coupled with the base metal, and the defects of the nickel plated layer such as fine cracks or pin holes are removed by the heating despite the gas atmosphere for the heat treatment.

Heat-treated sample if wrought material is used as base metal

Sixth to Eighth Examples

The based metal, which is made of structural carbon steel having a carbon content of 0.25 mass % and which is cut, is subjected to electroless nickel plating, heated under the carburizing gas atmosphere at 880°C for 90 minutes, quickly cooled, and then subjected to tempering at 180°C for one hour. Three types of electroless nickel plating are performed, i.e., the phosphorus content of the nickel plated layer is low by mass percentage (a sixth example), intermediate (a seventh example), and high (an eighth

example). A thickness of the nickel plated layer in each of the sixth to the eighth examples is set at 7 micrometers.

Thicknesses of the nickel diffused layers obtained by analyzing cross sections of the heat-treated samples using the EPMA are 23 micrometers in the sixth example, 15 micrometers in the seventh example, and 10 micrometers in the eighth example. In the sixth example in which the phosphorus content of the sample is low, a cross-sectional structure is such that the deep portion at a distance of about 30 micrometers from the surface has a martensite structure, and is such that the central portion has a fine pearlite structure transformed by the heat treatment. By diffusing nickel into the iron matrix of the base metal, the hardenability of the nickel diffused region is improved. Further, in the eighth example in which the phosphorus content of the sample is high, the martensite structure is hardly recognized but the sample has a mixed structure of fine pearlite and ferrite. This is because the diffusion of nickel is low and carburizing is slight.

Cross-sectional hardnesses of the respective heat-treated samples in the sixth to the eighth examples are illustrated in Table 2 below.

Table 2

CROSS-SECTIONAL HARDNESS OF HEAT-TREATED SAMPLE (MHV)

DEPTH FROM SURFACE(mm)	0.05	0.1	0.3	0.5	1
SIXTH EXAMPLE	613	605	585	578	555
SEVENTH EXAMPLE	550	528	500	483	420
EIGHTH EXAMPLE	420	408	400	396	385

According to Table 2, the cross-sectional hardness of the

sample in the sixth example having the low phosphorus content is high, and that of the sample in the eighth example having the high phosphorus content is low. Corrosion resistances of the respective samples in the sixth to the eighth examples after the salt spray test are all high in a manner similar to that of the sample in the first example shown in Fig. 3A.

As can be seen, in the sixth to the eighth examples, the sample (sixth example) in which the nickel plated layer has the low phosphorus content has a large nickel diffusion depth and a large carburizing depth, and the sample is converted into a compact having a relatively large thickness. Therefore, a compact having the low phosphorus content is suitable particularly for a quenched part. The sample (the eighth example) in which the nickel plated layer has the high phosphorus content does not exhibit an improved hardenability. However, the thickness of the nickel diffused layer is 10 micrometers, and carburizing is conducted on the nickel plated layer and even on the nickel diffused layer. Therefore, the base metal can be reliably coupled with the nickel layer, the sample is excellent in corrosion resistance, and the nickel plated layer exhibits a relatively hard property.

Furthermore, the phosphorus contained in the nickel plated layer inhibits the carburizing of the nickel plated layer and the diffusing of nickel. Due to this, the phosphorus content of the electroless nickel plated layer can be used as one means of controlling the carburizing quantity and the nickel diffusion. It is noted, however, that if this means is used, it is necessary to appropriately select the phosphorus content of the nickel plated

layer in light of the appropriate cross-sectional structure, the appropriate cross-sectional hardness, and the appropriate nickel diffused state.

As can be understood from the respective examples, in a product which is obtained by subjecting the base metal made of the iron-based material to nickel plating, and then to the heat treatment under the gas atmosphere having carbon potential, the nickel contained in the nickel layer and the iron contained in the iron matrix are mutually diffused into the base metal and the nickel layer, respectively, the mechanical strength of the product is high, and the nickel layer and the base metal are coupled with each other with a high adhesiveness, thereby making it difficult to peel off the nickel layer from the base metal. Further, by carrying out the heat treatment, the nickel layer is carburized using the carbon contained in the gas atmosphere for the heat treatment or that contained in the base metal, transformed into a Ni-C alloy, that is, a soft phase slightly harder than nickel, and the defects of the plated layer are removed. If quenching is performed, the Fe-Ni-C alloy portion tends to have the martensite structure and the Ni-C alloy is hardened. If the base metal having a low carbon content or containing no carbon is used, an iron-based part having a hard surface layer portion and a soft central portion can be manufactured. Furthermore, if shot peening or barrel finishing is performed on the heat-treated compact, a part having a glossy surface can be manufactured.

CLAIMS

1. An iron-based part having a base metal made of iron or iron-based alloy comprising:
 - a surface covered with a nickel layer that contains carbon or a nickel layer that contains carbon and phosphorus;
 - a nickel diffused layer, in which a nickel content is lowered in a depth direction, formed on a base metal made of the iron or iron-based alloy; and
 - carbon contained in at least a surface layer of the nickel diffused layer.
2. The iron-based part according to claim 1, wherein the nickel diffused layer has a quenched metal structure including martensite.
3. The iron-based part according to claim 1 or 2, wherein the iron-based part is a mechanical element or a mechanism element required to have an abrasion resistance or a corrosion resistance.
4. The iron-based part according to any one of claims 1 to 3, wherein the iron or iron-based alloy is manufactured by using a wrought material or a sintered material.
5. The iron-based part according to claim 4, wherein the wrought material is structural carbon steel.
6. The iron-based part according to claim 4, wherein the

sintered material is Fe-Cu based alloy or Fe-Cu-C based alloy.

7. A production method for an iron-base part, the method comprising the steps of:

covering a surface of a base metal made of iron or iron-based alloy with a nickel layer;

heating the base metal to an austenite region temperature in an iron-carbon constitutional diagram under a gas atmosphere having a carbon potential of 0.1 to 1.2%; and

cooling the base metal.

8. The method according to claim 7, wherein after the base metal is heated to the austenite region temperature, quenching and tempering are performed.

9. The method according to claim 8, wherein heating of the base metal to the austenite region temperature is performed first in a first temperature for promoting carburizing and nickel diffusion, and is then performed in a second temperature lower than the first temperature, and the quenching is performed.

10. The method according to any one of claims 7 to 9, wherein the nickel layer is laminated by carrying out at least one of nickel electroplating and electroless nickel plating.

11. The method according to any one of claims 7 to 10, wherein the nickel layer is a nickel-phosphorus plated layer formed by the

electroless nickel plating and having a phosphorus content of 15 mass % or less, the phosphorus content is reduced if a carburizing quantity of the iron or iron-based alloy is to be increased, and the phosphorus content is increased if the carburizing quantity of the iron or iron-based alloy is to be reduced.

12. The method according to any one of claims 7 to 11, wherein the iron or iron-based alloy is manufactured by using a wrought material or an iron-based sintered material.