METHOD FOR MANUFACTURING STEEL PLATES COATED WITH ALUMINUM POWDER

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Filed: Aug. 9, 1971

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ABSTRACT

A method for rapidly and continuously manufacturing steel plates coated with aluminum powder wherein the plates are cleaned and coated with a slurry of aluminum powder in water, dried, rolled between special internally water-cooled rolls to achieve substantially theoretical density of the coated aluminum and then heat treated at between 450°C and 700°C for 1–5 seconds in either a specially controlled high frequency induction furnace or a radiation tube type furnace or combination of both.

4 Claims, 6 Drawing Figures
METHOD FOR MANUFACTURING STEEL PLATES COATED WITH ALUMINUM POWDER

The present invention relates to manufacturing steel plates coated with aluminum powder and an apparatus to be used therein.

According to the prior art, a steel plate to be coated with aluminum powder is heated in a medium having very low thermal conductivity as an oxidizing atmosphere, a non-oxidizing atmosphere or a reducing atmosphere.

For example, U. S. Pat. No. 3,382,085 discloses a method of coating 0.10 inches thick and 6 inches wide coil with aluminum by heating it in a semi-muffle furnace at 500°C for 1 hour. French Patent No. 66,915 discloses a method of coating steel plates with a mixture of zinc and aluminum powders by heating in a 100 percent hydrogen atmosphere either at 316°C - 454°C for 6 hours or at 316°C - 557°C for 24 - 48 hours. Japanese Patent Publication No. 40/431 disclosed that a steel plate may be coated with aluminum, subjected to mechanical working with a reduction of 35 - 70 percent and heated at an arbitrary temperature within the range 400°C - 700°C for an arbitrary period within the range of 1 second to 1 hour so as to prevent forming of an alloy layer or to limit such an alloy layer, if formed, to be less than 3 μ thick by heat treatment. According to the disclosure of Japanese Patent Publication No. 44/20841, a steel plate may be coated with aluminum, by heating in a non-oxidizing atmosphere or reducing atmosphere at a temperature less than that of melting point of aluminum for a short period of time to perform a preliminary sintering, then a pressure with a reduction rate of less than 10 percent to compact the aluminum layer and heating as well as sintering at 350°C - 500°C.

According to these prior art methods, it takes a considerable time to heat steel plates up to a predetermined temperature (heat treatment temperature) because the steel plates are heated in a gas having very low thermal conductivity. Continuous operation from rolling to heat treatment, consequently, requires heating to an unnecessarily high temperature or in a furnace having a long oven length. Such a furnace has a high construction cost, and raising the atmosphere temperature in a short time will also raise the production cost.

In manufacturing steel plates coated with such metal powders as aluminum powder, steel plates are subjected to a pretreatment such as degreasing with alkali, washing in water, pickling, etc., then coated with a slurry consisting of metal powders and water, and then dried, rolled and heated. In the prior art, it is difficult to perform rapid and continuous processing efficiently as respective stages of drying, rolling and heat treatment all require considerable time.

In any of the above prior art processes so much steam is generated in drying the slurry of metal powder coated on the steel plates that drying speed is considerably slowed down particularly when drying is carried out only by means of an induction heating, thus bringing about inefficiency. In order to accelerate drying, generated steam must be exhausted rapidly from the furnace and air must be blown into the same simultaneously. In a heating furnace used for drying slurry, coatings of metal powder and for heat treatment after rolling, the heating speeds, temperatures, etc., must be adjustable dependent on the thickness of strips, speeds of treatments, kinds of metals for coating and thicknesses of the coated layer. The conventional high frequency induction heating furnace has often been used only for heat treatment. A continuous heating furnace for strips, for drying coated layers mainly consisting of aqueous solution, in which temperature is arbitrarily adjustable, has not yet been proposed.

In coating with metal powders, metal powders mixed with water or solvent and binder in a form of a slurry are painted or electrostatically coated on steel plates. In any of these cases, the coated steel plates are subjected to a heat treatment for drying and sintering the coated layer prior to rolling, and the steel plates coated with metal powder are continuously rolled after the heat treatment.

In the prior art, when rolling such heated steel plates, the surfaces of the rolls are cooled and smoothed by means of water or a rolling lubricant oil. However, when the rolls are cooled from the outside the metal powder coated on the steel plates may possibly flow out from the same thus preventing formation of the desired coated layer. In the absence of a cooling operation, the surface temperature of the rolls becomes too high, so that the metal powder easily adheres to the rolls thus it is impossible to obtain a uniform and smooth layer. Moreover, the lubricating properties of the grease in the ball bearings is damaged at high temperatures.

The present invention aims to substantially eliminate the defects of the prior art. An object of the present invention is to provide a method of continuously manufacturing aluminum-coated steel plates having excellent adherence, wherein steel plates to which aluminum powder is applied are rolled to comminate the aluminum powders sufficiently and density to a nearly theoretical density (the same density as that of pure aluminum sheet), thus forming a continuous aluminum layer thereon, and subjected to a rapid heat treatment.

Another object of the present invention is to eliminate defects of the prior art processes of drying, rolling and heat treatment and to provide a rapid and continuous method of manufacturing aluminum-coated steel plates.

Still another object of the present invention is to eliminate defects of the prior art heating furnace used for manufacturing steel plates coated with metal powder.

Still another object of the present invention is to eliminate defects of the conventional rolls and to provide novel hollow compacting rolls wherein cooling water is circulated to cool the same and the ball bearings thereof are provided with rotary joints which facilitate the supply and drainage of water to and from the bearings while the rolls are rotating.

The present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 schematically shows the whole process for manufacturing steel plates coated with aluminum powder;

FIG. 2 is a diagram showing conditions for heat treatment;

FIG. 3 is a diagram showing the temperature rises in various heating furnaces;

FIG. 4 shows a longitudinal section of a high frequency induction heating furnace;
In FIG. 1 steel strip (A) is transferred to a pretreatment tank 9 through a pay-off reel 1, a feeder leveller 2, a pinch roll and shearing device 3, a welder 4, the first bridge 5, an entry side looper 6, the second bridge 7 and a tension unit 8. In the pre-treatment tank 9 the strip is subjected to degreasing with alkaline, washing in water, pickling, washing in water and water scrubbing. Degreasing and pickling may be conducted by either the dipping method or the electrolytic method dependent on the conditions of the surface of the steel strip. After the pre-treatment hot air is blown onto the strip from a drier 10 to rapidly dry the surfaces thereof in order to prevent rusting and to facilitate painting of a slurry of aluminum powder and water in the subsequent process.

The dried strip (A) is fed to a slurry coater 12 through the third bridge 11 to be coated with a slurry consisting of aluminum powder and water. The reverse type slurry coater is provided with devices for mixing aluminum powder and water and for circulating slurry to supply prepared slurry to the coater. As the slurry may be left as prepared for a long time before coating, there is a possibility that aluminum powder will react with water thereby making use of the slurry impossible. To prevent such a reaction, such slurry stabilizing agents as phytic acid, aluminum chloride, aluminum sulfate and malonic acid are added to the slurry. When steel strip is fed at a slow speed, rust may generate on the strip during the process time between coating of the strip with slurry and drying. Such rust is effectively prevented by addition of a corrosion inhibitor such as sodium nitrite and sodium benzoate.

The strip (A), coated with slurry, is fed to a rapid heating drying furnace from which the evaporating water is rapidly exhausted, in order to complete drying in as short a time as possible; the degree of drying must be uniform at the upper and lower surfaces of the strip without looping of the strips in the furnace; and exfoliation of dried aluminum powder caused by a supporting member for said looping must be prevented. A high frequency induction heating furnace provided with a device for exhausting vapour meets the foregoing requirements. The structure of the heating furnace will be described later in the specification.

The steel strip delivered from the drying furnace 13 is then fed to a rolling mill 14 where aluminum powder is completed and adhered to the surface of the steel strip. In rolling the strip, a considerable amount of the aluminum powder sticks to the rolls of the mill 14 not only spoiling the surface of the steel strip but also damaging the uniformity of the coated metal. In order to prevent such defects, hollow rolls of which are cooled from inside thereof are used. In addition, a roll cleaning apparatus is provided at the delivery side of the rolls to clean the surface of the rolls and remove aluminum powder stuck thereto.

The steel strip delivered from the rolling mill 14 is then fed to the heat treatment furnace wherein the strip is rapidly and continuously subjected to a heat treatment to impart to the aluminum layer resistance to bending, drawing, etc. Time and temperature for heat treatment depend on the thickness of the strip and the aluminum layer thereon. It is necessary to provide for rapidly changing temperature for heat treatment corresponding to changes in the production schedule. In one embodiment of the present invention a continuous high frequency induction heating furnace 15 and radiation tube type furnace 16 are employed as heating furnaces, but the invention is not limited thereto. In the embodiment, when the strip is thin and is rapidly coated with slurry, only the high frequency induction heating furnace 15 is employed while when the strip is thick and coated with slurry at a slow speed and must be heated for a long time, the radiation tube type furnace 16 as well as said high frequency induction furnace is employed to attain maintenance of desired temperature. In this way, temperature for heat treatment is adjusted continuously corresponding to the change of conditions for heat treatment caused by change in strip thickness and speed of coating by means of the combination of these two furnaces. Consequently, it is possible to conduct heat treatment in a simple manufacturing line and reduce the construction cost.

The steel strip delivered from the heat treatment furnaces 15, 16 is fed to a water quenching tank 17 which is provided with a water circulation device having a spray nozzle to maintain the temperature of water at the entry side of the tank 17 at a constant value and with a wringer roll at the delivery side of the tank. The temperature of water for cooling the strip is adjustable in accordance with the requirements of the drying process. The strip is further fed to a post treatment tank 19, to impart to the strip a corrosion resistant property, via a drier 18. The drier 18 is used dependent upon the kind of chemical treatments to which the strip is subjected in said tank 19. The method of post treatment may be selected from among chromate treatment, chromate treatment with soluble organic high molecular compound, etc., by immersing or spraying.

The strip delivered from the post treatment tank 19 passes through a hot air blowing type drier 20, the fourth bridge 21, a delivery side looper 22, the fifth bridge 23 and a delivery side shear 24, and is fed to a tension reel 25 where the strip is coiled as a final product.

As has been described so far, the method of the present invention shortens drying and heat treatment processes, thus bringing about rapid and continuous manufacturing of aluminum-coated steel plates.

Rapid heat treatment will be described in further detail hereinafter.

FIG. 2 shows the relation between temperature of a steel plate and treatment time. The upper line in FIG. 2 represents the upper limit of heat treatment temperature for not forming an alloy layer of Fe and Al in the interface of the aluminum layer and the steel plate. If the hard and brittle alloy layer of Fe and Al is formed, cracks are easily caused in the coated layer on a steel plate while it is being formed. Moreover, aluminum-coated steel plate, treated under such conditions as to form an Fe — Al alloy layer, does not have the lustre peculiar to aluminum and becomes yellowish in color. Consequently, heat treatment at a temperature above the aforementioned upper limit is undesirable.

The lower line shown in FIG. 2 represents the lower limit of heat treatment temperature below which adherence between the aluminum layer and the steel...
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EMBODIMENT 4

A slurry comprising the same compositions as that of Embodiment 2 was continuously coated on a cold-rolled coil having a thickness of 0.8 mm and a width of 100 mm by a reverse system roll coater at a rate of dried weight of 80 g/m², and the coated coil was dried and rolled to 5 percent reduction rate. The coil was then heated for 2 seconds at a heating rate of 225°C/sec with an input power of 7 KW in an induction heating furnace having frequency of 10 KC, maintained at 550°C for 3 seconds with 0.5 KW and subjected to water quenching.

Aluminum-coated steel plate thus obtained had the same excellent properties as Embodiment 2, having beautiful luster, excellent workability and resistance to corrosion.

EMBODIMENT 5

The rolled aluminum-coated steel plate obtained in the same way as Embodiment 4 was heated for 2 seconds in such a way that the temperature at the surface of the steel plate became 500°C with an input power of 7 KW in an induction heating furnace having a frequency of 10 KC and then heated for 3 seconds at 500°C in a furnace in the atmosphere. The steel plate thus obtained has luster on the surface thereof and no defects were seen in the coated layer in a deep drawing test. Though white rust was caused in a humidity cabinet test at 50°C and with 100 percent of moisture, red rust did not generate after a test for 3000 hours.

As has been described so far, aluminum powder coated on a steel plate is compacted to provide almost theoretical density, and subjected to heat treatment at a temperature within the range from 450°C to 700°C for 1–5 seconds. As the result of the foregoing, time for heat treatment is remarkably shortened. Further, it is possible to shorten furnace length and to conduct rapid and continuous operation. Moreover, operation is easily performed at low cost because heat treatment is conducted in the atmosphere and heating in a non-oxidizing or reducing atmosphere is unnecessary. Heat treatment under these particular conditions prevents forming a hard and brittle alloy layer, damaging the luster peculiar to aluminum or causing insufficient adherence.

The present invention is characterized by the above-mentioned rapid heat treatment. An embodiment of a high frequency induction heating furnace will be described hereinafter reference being made to FIGS. 4 and 5 of the accompanying drawing.

In the drawing, 40 denotes a steel plate coated on both surfaces with a slurry consisting of aluminum powder and water, which is fed to a heating furnace 41 as shown in FIG. 4. The heating furnace is equipped with a hot air blowing device 42 at the entry side thereof, where the hot air heated up to 80°–100°C is applied to the steel plate entering the heating furnace 41 to accelerate drying. 43a, 43b and 43c denote coils for high frequency induction heating. Inductance at the respective coils 43a, 43b and 43c is continuously adjusted to facilitate to continuously vary the curve of temperatures at the respective coils independently of each other by means of the respective control systems which are respectively independent of each other. Thus, input power to the respective coils for heating is made adjustable at loading. As shown in FIG. 5, the coils 43 com-

plate is not sufficient and exfoliation of the aluminum layer or minute cracks therein are caused during working of the aluminum-coated steel plate. Thus, the intermediate part between the upper and lower lines shown in FIG. 2 is the optimum range for the heat treatment. Aluminum-coated steel plates having excellent properties, in which no cracks are caused in the aluminum layer, are obtained by heat treatment under the conditions within the above range. By further examining the said range to obtain better and more economical conditions for a continuous process of manufacturing aluminum-coated steel plate comprising painting, roll and heat treatment, the range (B) indicated by oblique lines in FIG. 2 is obtained. The present invention is characterized by rapid heat treatment under the conditions within the range (B).

Heat treatment under such conditions is impossible by the conventional heating method with gases.

In order to attain such a heat treatment for the present invention, suitable heating methods are: (a) heating aluminum-coated steel plates with a metal having both good heat conductivity and not reacting with aluminum; (b) heating by means of induction heating as described in reference to FIG. 1; or (c) rapidly heating the steel plate up to a predetermined temperature by induction heating and maintaining the same at the temperature in a furnace containing gas therein. Rapid heat conduction is effected by a metal bath, such as a lead bath or an induction heating furnace, and steel plates are heated up to a predetermined temperature in a short time. FIG. 3 shows the manner in which the temperature rises in some heating furnaces. In FIG. 3, (a) shows a case of heating with a lead bath, (b) heating in an induction heating furnace, (c) in a combination of an induction heating furnace and a silicon nitride furnace and (d) in a silicon nitride furnace.

Other embodiments of the present invention will be described hereinafter.

EMBODIMENT 2

A slurry consisting of atomized aluminum powder comprising particles having an average particle size of 15 μ and an aqueous solution of NaNO₂ having a concentration of 10⁻² mole/l, mixed in the ratio of 6:4, was coated on a steel plate by means of a reverse roll coater. The coating rate was 80 g/m². Then the steel plate was dried and rolled in a rolling mill so as to reduce the steel plate by 5 percent. The aluminum-coated steel plate thus obtained was subjected to oil quenching after heat treatment for 3 seconds in a lead bath which was maintained at 600°C. The steel plate thus obtained had the metallic luster peculiar to aluminum and no cracks were caused in the coated layer in bending tests to an angle of 180°. In a salt spraying test (Japanese Industrial Standard Z-2371), red rusts did not appear at all, even after being subjected to a test for 200 hours. Thus, it is shown that the steel plate has an excellent corrosion resistant property.

EMBODIMENT 3

A rolled aluminum-coated steel plate obtained in the same way as Embodiment 2 was subjected to heat treatment for 5 seconds in a lead bath maintained at 550°C, and then to water quenching. Aluminum-coated steel plate having the same properties as Embodiment 2 was obtained.
prise an outer protective insulating wall 44 for mechanical protection of the coil and prevention of dust and danger, and an inner protective insulating wall 45 which is exchangeable for mechanical protection of the coils 43 when the strip 40 is damaged and to prevent slurry which is not dried yet from dropping directly on the inside of the coils 43 and adhering thereto. Connecting devices for exhaust 46a, 46b and 46c are provided at the delivery side of the heating furnace 41 and between the respective coils 43a, 43b and 43c. These exhaust devices 46 which are connected to exhaust blowers accelerate drying by exhausting vapours and gases which are generated upon heating from the top and bottom ends of the devices 46. Windows 47a, 47b and 47c are provided in the connecting devices 46a, 46b and 46c to watch the state of drying within the heating coils 43 so that the load on the heating coils can be adjusted if necessary.

As is described hereinafter, the high frequency induction heating furnace of the present invention comprises a plurality of high frequency induction heating coils which facilitate independent control of the temperature curve by means of the control systems which are independent of each other, the hot air blowing device at the entry side of the heating furnace, and the connecting devices for exhaust between respective coils and at the delivery side of the furnace. Thus, a great deal of vapour and gas generated when slurry containing aluminum powder coated on the steel strip is dried is exhausted through the exhaust device to promote drying and effective heating. At the time of drying and of heat treatment after rolling, heating speed and temperature are adjusted to provide the optimum conditions for each coil depending upon the thickness of the strip which is being treated, the number of heating coils which can be controlled independently of each other, the kind of coated metals and the thickness of coated layer.

An embodiment of rolling rolls which are employed in the rolling process will be described hereinafter, reference being made to FIG. 6.

In FIG. 6, 51 denotes a lower work roll and 52 denotes an upper work roll. A steel strip coated with aluminum powder and subjected to heat treatment is rolled between said upper and lower rolls 51, 52. 53 denotes ball bearings to support said rolls 51, 52.

The rolls 51, 52 are provided with a hollow portion 54 extending in the axial direction and one end of which is closed, in which a water supply tube 55 supported by a receiving member 56 at the closed end of the hollow portion 54 is provided in the center thereof. A plurality of water supply apertures 57 are provided in the water supply tube 55. Cooling water is supplied to the inside of the hollow portion 54 through the apertures 57 of the water supply tube 55 to cool the rolls 51, 52.

58 denotes a rotary joint connected to the open end of the hollow portion 54 in the rolls 51, 52, comprising double rotary sleeves 60, 61 installed in the fixed casing 59, ball bearings 62, 63 to support said two rotary sleeves 60, 61, and flexible hoses 64, 65 to supply said sleeves with cooling water.

The end of the rolls 51, 52 is fixed to the outer rotary sleeve 60 in a liquid-tight manner, and the gap between the outer rotary sleeve 60 and the inner rotary sleeve 61 is connected to the hollow portion 54 and the flexible hose 65 for drainage of cooling water supplied in the hollow portion 54. The water supply tube 55 is connected to the inner rotary sleeve 61 at one end thereof and the other end of the inner rotary sleeve 61 is opened to a cover 66 which is fixed to the fixed casing 59 and in which the flexible hose 64 for supplying water is connected.

Cooling water supplied through the flexible hose 64 is fed to the water supply tube 55 through the inner rotary sleeve 61 and to the hollow portion 54 from the water supply apertures 57. Water fed to the hollow portion 54 and cooling the rolls 51, 52 is drained from the flexible hose 65 through the gap 67 in the outer rotary sleeve 60.

As above-described, the rolls are cooled from the inside thereof. Therefore, coated aluminum powder is not washed away by cooling water or lubricant oil as often happened in the prior art, nor does it adhere to the rolls and damage the uniform surface of the rolled steel strip.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a method of manufacturing steel plates coated with aluminum powder, in which both surfaces of a steel strip are cleaned, coated with a slurry consisting essentially of aluminum powder and water, dried, rolled to compact said aluminum powder to the steel strip to the extent that substantially theoretical density of aluminum is achieved, heat treated and post treated to give resistance to corrosion to the strip, the improvement comprising conducting said heat treatment at 450°-700°C for 1-5 seconds.

2. A method of manufacturing steel plates coated with aluminum powder as claimed in claim 1, wherein said steel strip coated with said slurry is dried in a high frequency induction heating furnace provided with a device for exhausting vapour.

3. A method of manufacturing steel plates coated with aluminum powder as claimed in claim 2, wherein heat treatment is carried out in a molten metal bath having good heat conductivity and which does not react with aluminum.

4. A method of manufacturing steel plates coated with aluminum powder as claimed in claim 1, wherein heat treatment is carried out in a molten metal bath having good heat conductivity and which does not react with aluminum.

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