ABSTRACT OF THE DISCLOSURE

A method and apparatus for continuous coating of a metal substrate with a molten metal in which a metal substrate is successively annealed at an elevated temperature in a heating zone, cooled in a cooling zone and coated with a molten metal in an immersion zone, wherein the heating zone, the cooling zone and the immersion zone are maintained under a vacuum.

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a method and apparatus for coating metal substrates with molten metal and to the coated metal substrates so produced. More particularly, the present invention relates to a method and apparatus for coating steel wire with metals, such as copper, tin, lead or aluminum; and to the coated steel wire so produced.

Description of the prior art

In conventional processes of metal coating or metallizing, a metal substrate is subjected to a relatively large number of separate treatments. In a typical process, for example, steel wire is first annealed in order to obtain the desired degree of toughness and tensity strength. Thereafter, the annealed steel wire is ordinarily pickled and rinsed, processed with a salt solution or flux, dried, dipped into the proper metallizing bath and then cooled down. The purpose of the pickling step is to remove grease, dirt and the like, as well as oxides which may be formed during the heat treatment. The fluxing step is employed to provide the wire with good moistening characteristics for the liquid coating to be subsequently applied.

A conventional process for metal coating or metallizing of the type described above suffers from a number of disadvantages. For example, oxidation which occurs during the heat treatment is disadvantageous because it requires the additional pickling step. Further, the pickling and fluxing steps are disadvantageous because the metal substrate thereafter needs to be dried.

A further disadvantage results from the fact that after the annealing process the substrate is subsequently cooled down to the temperature of the rinsing and washing water during the pickling, rinsing and fluxing treatments. Thus, when the metal substrate is thereafter passed through the metallizing bath it absorbs a substantial amount of the heat present in the metallizing bath. Consequently, it is necessary to supply the metallizing bath continuously with a large quantity of heat in order to balance the removal of heat absorbed by the substrate and to maintain the temperature of the metallizing bath at a constant level.

A further disadvantage of the conventional type of process results from the fact that pickling with hydrochloric or sulfuric acid entails substantial difficulties with respect to providing the necessary apparatus for the removal of harmful vapors and used acid. In addition, treatment of the metal wire with salt solutions or flux is also disadvantageous because it causes sludge deposits to form in the metallizing bath.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for continuous coating of a metal substrate with a molten metal wherein the metal substrate is coated with molten metal in an immersion zone maintained under vacuum. More particularly, the metal substrate under vacuum is successively annealed at an elevated temperature in a heating zone, cooled in a cooling zone and coated with the molten metal in the immersion zone.

It is an object of the present invention to provide an improved process for coating metal substrates with molten metal which is simpler and less expensive than prior art processes.

It is another object of the present invention to provide improved apparatus for coating metal substrates with molten metal which is simpler and less expensive than apparatus of the prior art.

It is still another object of the present invention to provide improved metal-coated metal products.

Other objects and advantages of the present invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of an apparatus for continuous heat treatment and metallizing in accordance with one embodiment of the present invention; and

FIG. 2 is a schematic illustration of an apparatus for continuous heat treatment and metallizing in accordance with a second embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Apparatus for continuous heat treatment and subsequent metallizing of a metal substrate, namely, wire 1 is illustrated in FIG. 1. The metal substrate which may be utilized in the present invention includes any wire, strip, plate or similar extended form of metal product which it is desired to coat with a molten metal or to metallize. The metal wire 1 is fed from supply spool 2 and via guide rollers 3, 4 and 5 to a capstan 6. Guide roller 4 is mounted in an immersion bath 7 containing a molten coating metal.

The basic metal treating operations are carried out in a vacuum chamber 8. The supply spool 2 and/or capstan 6 may be mounted inside or outside the vacuum chamber 8. The required vacuum in vacuum chamber 8 may be obtained and maintained by any conventional means, as, for example, by means of the process described in U.S. Pat. No. 2,384,500. The vacuum may be obtained by connecting conventional pumps or other conventional equipment for producing a high vacuum, to vacuum chamber 8 by means of conduit 9.

A heater 10 is provided in chamber 8 to heat wire 1. The heater 10 may be of any conventional design where-by wire 1 may be heated, for example, by radiation, electron bombardment, direct resistance heating or the like. Chamber 8 is also provided with cooling means 11 for cooling the heated or annealed wire 1. Cooling apparatus 11 may be composed of water-cooled rollers or any other conventional suitable cooling apparatus. The apparatus of the present invention may also include a means H2 for introducing a reducing gas such as hydro-
3,728,144

3. The particular type of coating metal which may subsequently be employed.

After the wire 1 has been annealed and cooled as described above it is passed into the immersion bath 7 containing a molten metal. The coating metals which can be most advantageously employed in the present invention, are metals with a low vapor pressure in the proximity of their melting temperature, such as, for example, aluminum, copper, tin and indium or alloys of these metals. The temperature of the coating metal in the bath 7 is preferably kept at a temperature level that is approximately 1 to 50° C. higher than the melting temperature. In this way only a small amount of metal will be lost through evaporation with the result that the amount of metal deposition on the walls of vacuum chamber 8 is minimized and further the best coating layers with the lowest percentages of intermetallic combinations are obtained. The following table lists the melting temperatures, the vapor pressure and evaporation speeds of a number of metals with low vapor pressures which may be utilized in the present invention:

<table>
<thead>
<tr>
<th>Melting</th>
<th>Vapor</th>
<th>Appropriate</th>
<th>Approximate</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature,</td>
<td>pressure,</td>
<td>evaporation</td>
<td>evaporation</td>
<td>evaporation</td>
</tr>
<tr>
<td>°C</td>
<td>torr</td>
<td>speed in</td>
<td>speed in</td>
<td>speed in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>grams/sec.</td>
<td>grams/sec.</td>
<td>grams/sec.</td>
</tr>
<tr>
<td>Copper</td>
<td>1098</td>
<td>2 x 10^-6</td>
<td>7 x 10^-6</td>
<td>3 x 10^-6</td>
</tr>
<tr>
<td>Ti0.2Cu</td>
<td>232</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
</tr>
<tr>
<td>Lead</td>
<td>327</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
</tr>
<tr>
<td>Aluminum</td>
<td>650</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
<td>1 x 10^-6</td>
</tr>
</tbody>
</table>

In some cases, for example, with an aluminum coating it is advantageous to add a small percentage, e.g. 2 to 4 percent, of silicon to the immersion bath 7 in order to limit the formation of a reaction layer between the base and the coating metals. Other metals which have a relatively high vapor pressure, such as zinc, may be employed in the present invention but are less desirable than metals having lower vapor pressures. For example, zinc has a melting temperature of 420° C., a vapor pressure of 0.16 torr, and an evaporation speed in grams per second cm. of 10^-3.

In the practice of the present invention it is important that the wire 1, both before and during the dipping or coating in the bath 7, does not come into contact with the air. Thus, a strong reducing gas such as hydrogen may be injected under reduced pressure by means of a needle tap into the vacuum chamber 8 where the wire enters and leaves the metallizing bath in order to reduce potential formation of oxide layers on the metal wire 1. Also, it is usual advantageously to place the wire guide 5 between the guide roller 5 and capstan 6 so that the coated wire is cooled down to a relatively low temperature before it is wound around capstan 6. This cooling assists in preventing deformation of the coated wire 1 in the subsequent processing steps.

A series of tests were carried out at different wire feeding speeds to develop data correlating the thickness of the coating layer in relation to the wire feed speed. These curves show a decrease initially of the coating layer thickness at increasing speed, and show that subsequently at a higher speed a thicker coating layer is produced because of the dragging effect of the molten metal on the wire passed through the immersion bath. The coating layers obtained by the process of the present invention are of a high quality with respect to adhesion of the metal coating and resistance to chipping, as well as uniformity of coating thickness.

In a series of tests a mild steel wire (i.e., a wire with a low carbon content; namely 0.10%) was passed through a bath filled with molten aluminum. The temperature of the molten aluminum was about 670° C. and the vacuum maintained above the bath was about 5 x 10^-6 torr. The mild steel wire was first annealed at a temperature of about 850° C. and then slowly cooled down to a temperature of about 300° C. just before it was passed into the molten aluminum bath. In one of the
tests, the bath contained 0.0% silicon; in a second test, the bath contained 2.0% silicon; and in a third test, the bath contained 4.0% silicon. All of the wires coated in the above experiments were found to have a qualitatively good coating layer.

The present invention carried out as described above was found to have the following advantages over the processes of the prior art. First, it was found that in carrying out the heat treatment under vacuum no oxidation occurred; and further, that any grease and the like evaporated at the elevated temperature and reduced pressure employed. Further it was found that the metal substrate after annealing remains in a thermically etched state and is in excellent condition for thorough moistening in the molten metal bath. Also, it was found that it was not necessary to pickle, rinse, flux and dry the wire after annealing and before metal coating. In addition, since it was found possible to eliminate the pickling step there is no longer any danger or special equipment involved in the removal of harmful gases. Further, since no fluxing process was required, no sludge deposits were produced in the metallizing bath. Also, in view of the fact that the metal substrate when entering the metal bath is at an elevated temperature in the range of 400 to 600° C., which is substantially higher than in conventional processes, an important energy gain was realized. Finally, in view of all the foregoing advantages, it has been found that the production and installation expenses for an apparatus for coating a metal substrate with molten metal are substantially decreased.

While the foregoing describes two specific embodiments of the present invention it will be understood that the present invention is subject to the various modifications within the capabilities of the person skilled in the art. Thus, the present invention can be practiced with a variety of designs without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In a process for continuous coating of a metal substrate with a molten metal, the improvement which comprises annealing a substrate at an elevated temperature in a heating zone maintained under vacuum, cooling the annealed substrate in a cooling zone maintained under vacuum and coating the cooled annealed metal substrate with a molten metal in an immersion zone maintained under vacuum.

2. The invention as defined by claim 1 in which said substrate is annealed at a temperature above 700° C. in said heating zone.

3. The invention as defined by claim 1 in which said substrate is a carbon steel wire which is annealed at a temperature in the range of about 700 to 1000° C. in said heating zone and cooled to a temperature in the range of about 400 to 600° C. in said cooling zone.

4. The invention as defined by claim 1 in which said molten metal is maintained at a temperature up to 50° C. above its melting temperature.

5. The invention as defined by claim 1 in which a reducing gas is injected at reduced pressure into said immersion zone.

6. The invention as defined by claim 5 in which said reducing gas is hydrogen.

7. The invention defined by claim 1, in which said coating metal is a metal with a low vapor pressure at its melting temperature, said vapor pressure being no higher than about 3.2×10⁻³ torr.

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ALFRED L. LEAVITT, Primary Examiner
J. R. BATTEN, Jnr., Assistant Examiner

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