Sept. 23, 1969 A. P. FEDERMAN 3,468,695

METHOD OF COATING A STEEL BASE WITH ALUMINUM

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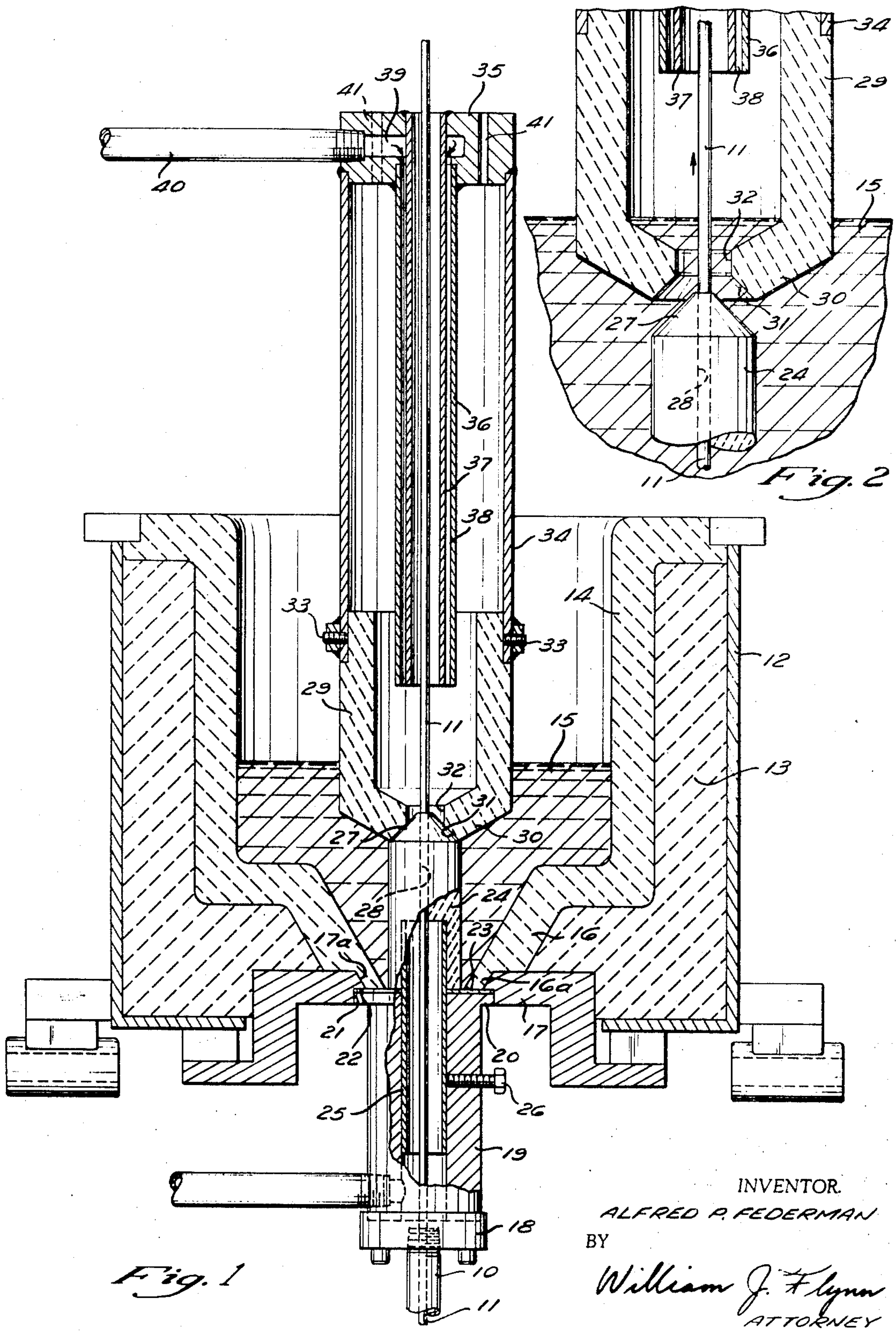

Fig. 1

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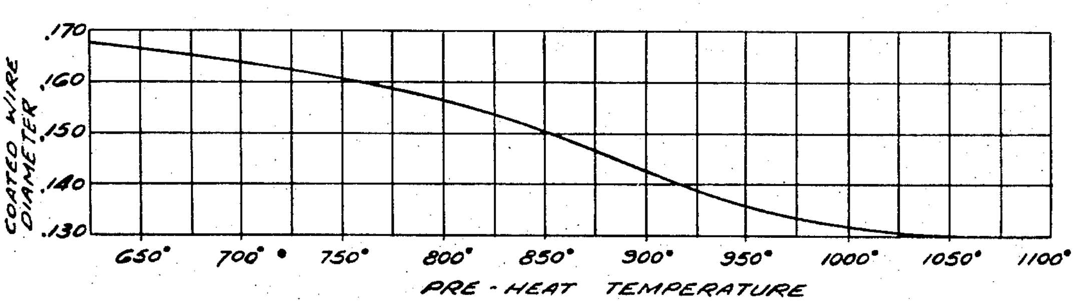

Fig. 3

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METHOD OF COATING A STEEL BASE WITH ALUMINUM

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ABSTRACT OF THE DISCLOSURE

The present invention provides a steel wire with a thick, smooth, concentric aluminum coating substantially free of dissolved iron and having a thickness greater than .002 inch and bonded to the steel at an interfacial alloy layer whose thickness is not more than .0007 inch. Before being coated, the steel wire is preheated in a reducing atmosphere to a temperature within the 500° F.–960° F. range. For minimum interfacial alloy layer thickness, the preheat atmosphere preferably is carbon monoxide. After being preheated and without exposure to air, the wire is passed through a bath of molten aluminum for a time interval sufficient to deposit the thick aluminum coating, but not long enough to permit substantial remelting of the deposited coating within the bath.

This invention relates to a method for depositing a metal coating on a metal base, particularly an aluminum coating on steel wire. By "aluminum" as used herein is meant substantially pure aluminum and also various aluminum alloys, preferably those which have high electrical conductivity and/or corrosion resistance.

Prior to the present invention, various difficulties and disadvantages have been encountered in the application of a thick aluminum coating to steel wire on a commercially practical, mass production basis. In accordance with the present invention, the difficulties and disadvantages of prior processes are substantially overcome by casting a thick, smooth surfaced aluminum coating onto steel in a novel and advantageous manner. By "thick" is meant substantially greater than .002 inch. The aluminum coating preferably is bonded to the steel base at an aluminum-steel interfacial alloy layer which may be intermittent or continuous over the entire surface of the steel base and which has a thickness throughout its extent of less than .0007 inch. Alternatively, the interfacial alloy layer may be substantially or completely absent and the thick aluminum coating may not be firmly bonded to the steel base, so that subsequent mechanical working and/or heat treatment will be necessary to bond the coating tightly to the base.

Aluminum-coated steel wire produced in accordance with the process of the present invention is characterized by an exceptionally smooth and concentric thick aluminum coating which has a controllable thickness.

It is a principal object of this invention to provide a novel and improved method of casting a thick, smooth, uniform thickness coating of aluminum onto steel.

Another object of this invention is to provide a novel and improved method of depositing a metal coating on a metal base in which the interfacial alloy layer between the coating and the base may be controlled or substantially eliminated, if desired.

Further objects and advantages of this invention will be apparent from the following detailed description of a presently-preferred embodiment of the apparatus for carrying out the present process and of exemplary embodiments of the process itself as illustrated in the accompanying drawings.

In the drawings:

FIGURE 1 is a vertical axial section, with certain parts broken away for clarity, through the coating apparatus with the valve arrangement therein closed;

FIGURE 2 is an enlarged fragmentary section of this apparatus with the valve arrangement open; and

FIGURE 3 is a graph showing the coating thickness plotted against preheat temperature for a particular uncoated wire size, wire speed and coating bath temperature in accordance with the present invention.

The following detailed description is directed specifically to the casting of a thick aluminum coating on a solid steel wire of circular cross-section. By a "thick" coating is meant an aluminum coating substantially greater than .002 inch in thickness, and preferably having a cross-sectional area of at least 7% of the total cross-sectional area of the coated wire. This coating is substantially thicker than that produced by hot-dip processes of the prior art, in which the aluminum is molten when the steel wire leaves the aluminum bath and remains on the wire only due to its own surface tension. Typically, such hot-dip coatings are 0.002 inch or less in thickness and the aluminum coating is not substantially free of dissolved iron. The aluminum coating produced by the present process is appreciably thicker than that of hot-dipped coatings and the thickness of this coating enables the coated wire to be used for purposes different from those of the hot-dipped wire of the prior art, for example as electrical conductors. In addition the coating in accordance with the present invention is substantially free of dissolved iron.

Before the aluminum coating is cast on, the steel wire preferably is thoroughly cleaned. While the present invention is not limited to the following details of the cleaning operation, successful results have been obtained with the following sequence of cleaning steps:

(1) subject the steel wire to a stream of shot or abrasive to remove any drawing compound on the wire;
(2) immerse the wire in an alkaline cleaning solution, with or without electrolytic action;
(3) rinse the wire in cold tap water;
(4) pickle the wire in a pickling solution heated to a temperature between 140° F. and 150° F. and agitated by an ultrasonic transducer;
(5) rinse the pickled wire in cold tap water; and
(6) finally, rinse the wire with hot distilled or de-ionized water.

The cleaned steel wire then is passed through a preheat furnace. This furnace includes an elongated tubular housing **10**, whose upper end only appears in FIG. 1. The wire **11** extends centrally longitudinally through this housing. The preheat furnace housing **10** is filled with a suitable gaseous oxygen-deficient or reducing atmosphere, such as hydrogen or carbon monoxide. This gas is maintained at above-atmospheric pressure by pumping in a continuous stream of the gas and permitting it to leak out of the lower end of the housing **10**. The escaping gas preferably is ignited as a safety measure. A suitable heat source, such as gas burners or an induction heating unit, is positioned in proximity to the housing **10** to heat the wire **11** to a suitable preheat temperature, as explained hereinafter. A series of thermocouples or optical pyrometers, not shown, are provided at intervals along the length of the housing **10** to sense the wire temperature, and suitable controls, not shown, may be provided for regulating the wire preheat temperature.

After being preheated, the steel wire **11** immediately passes vertically up through a casting furnace in accordance with the present invention.

Referring to FIG. 1 this casting furnace includes a crucible comprising a fixedly supported, generally cup-shaped outer shell **12** of steel or other suitable metal which supports a first refractory ceramic liner **13**. Liner

13, in turn, supports a generally cup-shaped, refractory, ceramic inner liner 14, which receives a pool or bath 15 of molten aluminum. At its lower end, the inner liner 14 has an inwardly offset, inwardly and downwardly tapering annular portion 16, which rests on a thick metal base member 17 of the casting furnace. This lower end portion 16 of the inner liner 14 terminates in a tapering annular nose portion 16*a* disposed inside a complementary opening 17*a* in the base member 17.

The upper end of the preheat furnace housing 10 is threadedly received in an annular steel flange 18, which is bolted to the lower end of a steel sleeve 19. An enlarged annular flange 20 on the upper end of this sleeve is snugly received in a complementary, downwardly-facing recess 21 formed in the bottom of base member 17. Base member 17 presents a downwardly-facing annular shoulder 22 at the intersection of its recess 17*a* and 21, this shoulder being coplanar with the bottom face of the lower nose portion 16*a* on the inner liner of the furnace. A flat, annular, refractory washer 23 is engaged between the top face of flange 20 and shoulder 22 and the bottom face of nose portion 16*a*.

A refractory ceramic tip 24 extends vertically upward within, and spaced from, the inner ceramic liner 14 of the casting furnace. A stainless steel tube 25 is rigidly secured in the ceramic tip 24, such as by being cast in place therein. Tube 25 extends down into sleeve 19 coaxial therewith. A plurality of bolts 26 clamp the tube 25 within sleeve 19. The ceramic tip 24 terminates at its upper end in an upwardly-facing, frusto-conical surface 27 which forms part of a valve assembly in this apparatus. The tip 24 has a central longitudinal passage 28 which snugly, but slidably, receives the steel wire 11. In one practical embodiment, for wire having a diameter of .128 inch, the diameter of this passage 28 was .139 inch.

The other part of this valve assembly is constituted by a vertically disposed, annular, refractory ceramic member 29 having a laterally inwardly turned lower end 30 terminating in a downwardly-facing frusto-conical surface 31, which is complementary to, and sealingly engageable with, the surface 27 on the upper end of the ceramic tip 21. Member 29 has a central, vertical opening 32 extending upward from this sealing surface 31.

Ceramic member 29 is attached by screws 33 to the lower end of a metal sleeve 34. The upper end of this sleeve is closed by an end cap 35. End cap 35 supports a pair of spaced, depending, concentric, vertically disposed metal tubes 36 and 37. The annular space 38 between the outer tube 36 and the inner tube 37 communicates with a cavity or recess 39 formed in the end cap 35. A pipe 40 communicates with recess 39. The upper end of the inner tube 37 is open to the atmosphere at the top of the end cap 35. The end cap itself has a plurality of narrow vent openings 41.

When the apparatus is in operation, a suitable gas, preferably nitrogen or argon, is introduced at pipe 40 and flows under pressure down through the space 38 between the outer and inner tubes 36 and 37, filling the space within the ceramic member 29 and sleeve 34 and escaping to the atmosphere through the open upper end of the inner tube 36 and through the vent openings 41 in end cap 35.

The unitary assembly of ceramic member 29, metal sleeve 34, end cap 35, tubes 36, 37, and pipe 40 is mounted for movement vertically up and down to selectively position the frustoconical sealing surface 31 on ceramic member 29 either in sealing engagement with the top surface 27 on the ceramic tip 24, as shown in FIG. 1, or spaced upward therefrom, as shown in FIG. 2. Thus it will be seen that the ceramic members 24 and 29 together constitute a valve which controls the flow of molten aluminum from the bath 15 into the interior of ceramic member 29.

Before the casting operation, the ceramic member 29 is in its "down" position, with its surface 31 sealingly engaging the top surface 27 of tip 24. Before there is any

molten aluminum 15 in the furnace, or before molten aluminum in the furnace reaches the level of the seal between ceramic member 29 and ceramic tip 24, the interior of ceramic member 29 and sleeve 34 is purged of air by continuously circulating nitrogen or argon under pressure through it. When the molten aluminum bath 15 is provided, the molten aluminum is prevented from flowing up into the interior of ceramic member 29 by the seal between the valve faces 27 and 31.

The cleaned and preheated steel wire 11 is fed up through the passage 28 in ceramic tip 24 and thence up through the interior of ceramic member 29 and up through the inner tube 37 and out through the top end cap 35. Any suitable wire feeding mechanism may be provided for this purpose. Preferably, the wire feed is maintained at a closely regulated, uniform speed.

When coating of aluminum onto the steel wire is to begin, the unitary assembly of ceramic member 29, metal sleeve 34, end cap 35, pipe 40 and tubes 36 and 37 is raised up to permit molten aluminum in the bath 15 to flow up between the valve surfaces 27 and 31 into the interior of ceramic member 29 to the same level as the main portion of the bath. The molten aluminum which has flowed up into member 29 is substantially free of oxides because this flow has taken place from below the level of the main bath 15. Even though the top surface of the main bath 15 is exposed to air and may be contaminated with oxides, there is substantially no oxide contamination of the molten aluminum below the surface. The molten aluminum which enters the ceramic member 29 remains oxide-free and uncontaminated because of the presence of the non-reactive gas in member 29.

As the steel wire 11 moves up out of the ceramic tip 24 and up through the molten aluminum inside the ceramic member 29, it picks up a uniformly thick, concentric coating of aluminum which adheres to, and solidifies on, the wire. The clearance or sliding fit of the steel wire 11 in the tip passage 28, the surface tension of the molten aluminum and the relatively low pressure head of the molten aluminum above the tip 24 are such that there is substantally no leakage or flow of the aluminum down the passage 28.

Preferably, the vertical depth of the molten aluminum bath above the top of the ceramic tip 24 is from about 5⁄16 inch to 3 inches. The wire speed is in excess of 50 feet per minute, preferably 100 feet per minute or higher. With a bath depth of ¾ inch and a wire speed of 100 feet per minute the steel wire is exposed to molten aluminum for .0375 second.

The bath 15 is replenished intermittently or continuously by adding more aluminum to the melt, so as to maintain substantially uniform the depth of the bath through which the wire must pass.

In accordance with the present invention, when using pure aluminum as the coating metal and a steel core wire .128 inch in diameter, the wire preheat temperature is within the range from 600° F. to 1200° F., and preferably within the range from 650° F. to 1000° F. For various aluminum alloys as the coating metal, the preferred preheat temperature range would be lower because of the lower melting point of such alloys. For certain alloys a preheat temperature as low as 500° F. may be permissible. When preheated to such a temperature and then passed immediately up through the aluminum bath, a smooth, concentric aluminum coating solidifies on the steel wire.

At preheat temperatures above about 625° F., in the case of pure aluminum as the coating metal, a steel core wire diameter of .128 inch, and a hydrogen atmosphere in the preheat furnace, the coating is bonded to the steel at a thin steel-aluminum interfacial alloy layer. While this interfacial alloy layer usually is not continuous over the whole surface extent of the steel wire, it is extensive enough to ensure an adequate bonding of the aluminum coating to the steel core wire, so that the coated wire subsequently may be redrawn through a drawing die, or otherwise mechanically worked or formed, such as in a rolling die.

Alternatively, at preheat in hydrogen below about 625° F., in the case of pure aluminum as the coating metal and a steel core wire diameter of .128 inch, this alloy layer tends not to form to a substantial extent, and consequently the aluminum coating may not be firmly bonded to the steel core wire. However, under such circumstances the aluminum coating can still be smooth and concentric, so that after subsequent heat treating to bond it to the steel core and drawing of the coated wire to the specified size, the coated wire is suitable for corrosion resistance or electrical conductivity purposes.

At preheat in hydrogen within the temperature range from about 625° F. to 1200° F., still with pure aluminum as the coating metal and a steel core wire diameter of .128 inch, the radial thickness of this interfacial alloy layer, where it is present, is within the range from about .0002 inch to .0007 inch, and usually, about .0003 inch. In general, the higher the preheat temperature, the thicker will be the interfacial alloy layer. Since the brittleness of the interfacial alloy layer increases with its thickness, it is preferable to keep its thickness about .0003 inch or less. When present, the interfacial alloy layer is so thin, and its formation is arrested so soon, that substantially no iron in the steel core wire dissolves into the aluminum bath or the deposited aluminum coating.

Where the interfacial alloy layer is to be minimized or substantially eliminated, carbon monoxide is preferred as the atmosphere for the preheat furnace. It is believed that the carbon monoxide absorbs oxygen from the surface of the steel core wire and tends to deposit carbon on the surface of the core wire which slows the wetting of the core wire and thereby reduces or prevents the formation of the interfacial alloy layer. At any rate, under otherwise identical conditions the use of carbon monoxide instead of hydrogen, as the preheat atmosphere results in a much smaller interfacial alloy layer. If desired, both carbon monoxide and hydrogen, preferably in that order because hydrogen reacts much more quickly with the surface of the steel core than does carbon monoxide, may be introduced into the preheat furnace to provide the preheat atmosphere.

In the case of a steel core wire which is not fully annealed, the tensile strength of the coated wire is less than that of the original uncoated steel core wire. The tensile strength varies inversely with the preheat temperature, the relationship being approximately a straight line relationship. That is, for a given increase in the preheat temperature there will be a generally proportionate decrease in the tensile strength of the coated wire. Where a high tensile strength is required, it will be necessary to redraw the coated wire. However, because the preheat temperature is not in excess of 1200° F. and preferably not in excess of 1000° F. the wire is not permanently reduced in tensile strength to an extent that would preclude its use (even after redrawing) for various purposes requiring high tensile strength, such as in suspended electrical power cables. This is extremely important because one significant practical application of the present invention is in high tensile strength aluminum-coated steel wire in which the steel core wire has been heat treated or otherwise processed to give it high tensile strength before the aluminum coating is deposited.

FIGURE 3 shows a plot of coated wire diameter versus preheat temperature for 1080 steel wire (0.80% carbon) having an original diameter of .128 inch, and pure aluminum as the coating metal. The coating thickness is a maximum at about 625° F. preheat. At this point the aluminum coating has a cross-sectional area of about 41% of the total cross-sectional area of the coated wire.

At temperatures below 625° F. the coating thickness of pure aluminum is not significantly greater than this, and the interfacial alloy layer is substantially absent, as already explained and the aluminum coating is not firmly bonded to the steel wire.

At a preheat temperature of about 860° F., in the case of this particular size and composition of the steel core wire, the pure aluminum coating has a cross-sectional area of about 25% of the total cross-sectional area of the coated wire.

At a preheat temperature of about 960° F., the pure aluminum coating has a cross-sectional area of about 10% of the total cross-sectional area of the coated wire.

For wires of different steel compositions and sizes, different compositions of the coating bath, different preheat and coating bath temperatures, and different periods of immersion of the core wire in the coating bath, the specific values of aluminum coating thickness for different wire preheat temperatures will differ from the particular values on the FIG. 7 curve, but the curve will be generally similar, with the coating thickness reaching a maximum at the minimum preheat temperature at which a smooth, continuous, concentric coating will be deposited, and declining gradually at progressively higher preheat temperatures up to about 1200° F. At preheat temperatures substantially above 1200° F. the aluminum coating is thin enough to be comparable to the coatings obtained by prior hot-dip coating processes.

As another specific example of the present invention, using the apparatus already described, 1080 steel wire (.80% carbon) of .128 inch diameter was preheated to 720° F. and passed through a pure aluminum bath at a temperature of 1260° F. The depth of the bath was 1$\frac{5}{16}$ inch. The immersion time was .608 second. The deposited coating was smooth and concentric, though not firmly bonded to the steel core. The coated wire had a diameter of .200 inch, so that the aluminum coating was 59% of the total cross-sectional area of the coated wire.

It appears, therefore, that the lower the coating bath temperature for a given preheat temperature, the thicker will be the deposited coating.

Also, as shown by FIG. 3, for a given both temperature, the lower the preheat temperature, the thicker will be the coating.

In the passage of the steel wire up through the aluminum bath, it appears that almost the complete thickness of the aluminum coating solidifies on the steel wire in the first few millimeters of the wire's travel through the bath. The preheated steel wire acts as a heat sink, absorbing heat from the molten aluminum in the bath to enable the aluminum to solidify onto the wire. The higher the temperature to which the wire is preheated, the less capacity it will have to absorb heat from the molten aluminum and, consequently, the thinner will be the solidified aluminum coating as shown by FIG. 3. Over a preheat temperature range from about 500° F. to 1200° F., if the time of immersion is short enough there appears to be no substantial remelting of the solidified aluminum within the bath as the steel core heats up, and as the wire emerges from the bath the aluminum coating is already substantially completely solidified thereon. This is in contrast to prior hot-dip processes in which the aluminum is largely still molten as the wire emerges from the bath and the molten aluminum is clinging to the wire primarily because of surface tension, with solidification of the aluminum taking place largely after the wire has emerged from the bath.

The depth of the aluminum bath through which the wire passes appears not to be critical, in and of itself. Successful results have been obtained with various immersion depths over the range from about 0.3 inch to 1$\frac{5}{16}$ inch and with wire speeds of from 11 to 144 feet per minute. As already pointed out, most of the aluminum apparently solidifies within the first few millimeters of the wire's travel through the bath, and a bath depth sufficient for this action to take place will be adequate. The bath depth should not be great enough to heat the steel core wire sufficiently to produce substantial remelting of the aluminum coating within the bath.

The speed of the wire through the aluminum bath also appears not to be critical, provided it is sufficiently high that the immersion time is not long enough for substantial remelting of the deposited aluminum coating within the bath. Successful results have been obtained with various wire speeds from 11 feet per minute to 144 feet per minute.

The time of immersion of the wire in the aluminum bath depends, of course, on the depth of the bath and the wire speed. Successful results have been obtained over a range of immersion times from about .03 to .6 second.

While it is greatly preferred to have the wire surface and the aluminum bath substantially oxide free where the wire enters the bath, adequate coatings have been obtained in the present invention in instancen where the steel wire was deliberately oxidized before being preheated in a reducing atmosphere.

While certain presently-preferred embodiments of the present process and a preferred embodiment of the present apparatus for performing this process have been described in detail herein and illustrated in the accompanying drawings, it is to be understood that various modifications, omissions and refinements which depart from the disclosed embodiments may be adopted without departing from the spirit and scope of this invention.

I claim:

1. A method of coating a steel base with an aluminum coating substantially thicker than .002 inch comprising the steps of:

preheating the steel base to a temperature within the range from substantially 500° F. to 1200° F.;

and, with the steel base preheated to said temperature, passing the steel base through a bath of molten aluminum for a time interval sufficient to deposit on the steel base a solidified aluminum coating having a thickness substantially greater than .002 inch, but insufficient for substantial re-melting of the deposited aluminum coating within the bath.

2. A method of coating a steel base with an aluminum coating substantially thicker than .002 inch comprising the steps of:

preheating the steel base in a reducing atmosphere to a temperature within the range from substantially 500° F. to 1200° F.;

and, with the steel base preheated to said temperature, passing the steel base through a bath of molten aluminum for a time interval sufficient to deposit on the steel base a solidified aluminum coating bonded to the steel base at an interfacial alloy layer and having a thickness outward from said alloy layer substantially greater than .002 inch, but insufficient for substantially remelting of the deposited aluminum coating within the bath and insufficient to require fluid spray quenching of the coated base when it emerges from the bath.

3. A method of coating steel wire with aluminum which comprises the steps of:

preheating the steel wire to a temperature within the range from substantially 500° F. to 1200° F.;

and, with the wire preheated to said temperature, passing the wire, through a bath of molten aluminum for a time sufficient to deposit on the steel wire an aluminum coating having a thickness substantially greater than .002 inch, but insufficient for substantial remelting of the deposited aluminum coating within the bath.

4. A method of coating steel wire with aluminum which comprises the steps of:

providing a bath of molten aluminum;

raising the temperature of the steel wire to within the range from substantially 500° F. to 1000° F. in a reducing atmosphere to preheat the wire;

and introducing the preheated steel wire into the bath beneath the surface of the bath and passing the wire through the bath for a period of time sufficient to deposit on the steel wire an aluminum coating which has a thickness substantially greater than .002 inch and which has a cross-sectional area at least 7% of the total cross-sectional area of the coated wire, but insufficient for substantial remelting of the deposited aluminum coating within the bath.

5. A method of coating a steel wire with aluminum which comprises the steps of:

preheating the steel wire in an oxygen-deficient atmosphere to a temperature within the range from substantially 500° F. to 1000° F.;

with the steel wire preheated to said temperature, introducing the wire into a bath of molten aluminum beneath the surface of the bath and passing the wire through the bath for a time sufficient to deposit on the steel wire an aluminum coating bonded to the steel wire at a thin interfacial alloy layer and having an aluminum thickness several times the thickness of the interfacial alloy layer and substantially greater than .002 inch, but insufficient for substantial remelting of the deposited aluminum coating within the bath;

and withdrawing the coated wire upward from the bath into an atmosphere at a temperature insufficient to melt the deposited coating.

6. The method of claim 5 wherein the wire passes through the bath at a speed in excess of 50 feet per minute.

7. A method of coating steel wire with aluminum which comprises the steps of:

providing a bath of molten aluminum;

raising the temperature of the steel wire in a reducing atmosphere to within the range from substantially 500° F. to 1200° F. to preheat the wire;

while maintaining the preheated steel wire in said last-mentioned reducing atmosphere, introducing the preheated steel wire into the bath beneath the surface of the bath and passing the wire through the bath at a speed in excess of 50 feet per minute;

and withdrawing the wire up from the bath after a total exposure to the bath insufficient for substantial remelting of the deposited aluminum coating within the bath and without quenching the coated wire with a fluid spray when it is withdrawn from the bath.

8. In a process of casting a thick coating of aluminum on a steel wire, the steps of:

preheating the wire in a reducing atmosphere containing substantial carbon monoxide at a temperature substantial below the melting point of aluminum;

and thereafter passing the preheated wire through a bath of molten aluminum for a time sufficient to deposit on the wire an aluminum coating substantially thicker than .002 inch but insufficient for substantial remelting of the deposited aluminum coating within the bath.

9. A process according to claim 8, wherein the wire is preheated in said reducing atmosphere to a temperature substantially within the range from 500° F. to 1200° F.

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