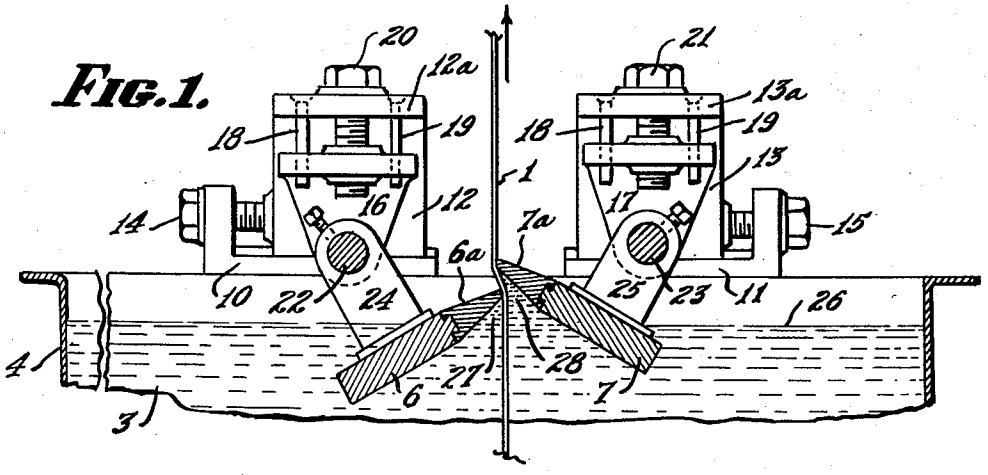
Nov. 24, 1959 K. OGANOWSKI 2,914,419

METHOD AND APPARATUS FOR CONTINUOUSLY COATING A METAL STRAND-LIKE ARTICLE WITH MOLTEN METAL

Filed Aug. 3, 1953

2 Sheets-Sheet 1

FIG. 1.



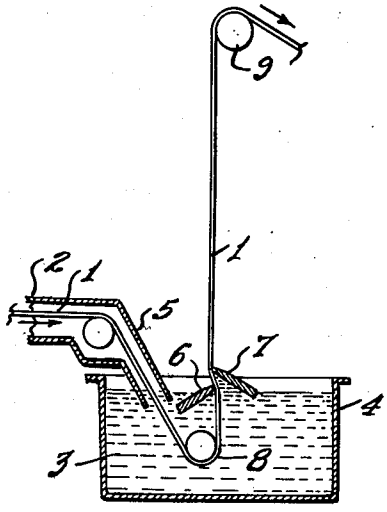


FIG. 2.

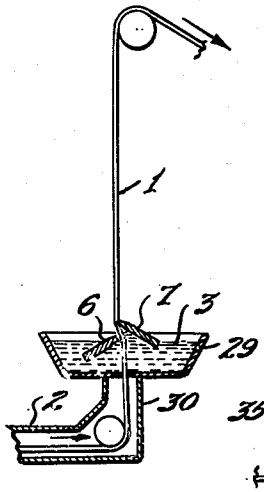


FIG. 3.

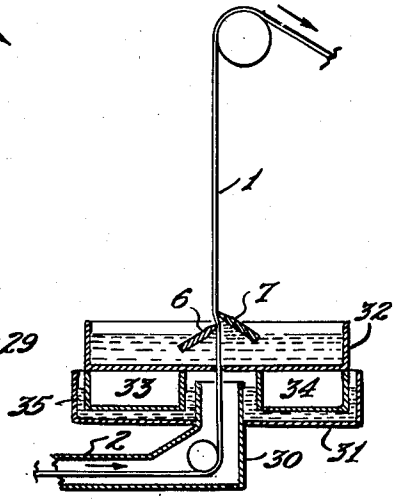


FIG. 4.

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2 Sheets-Sheet 2

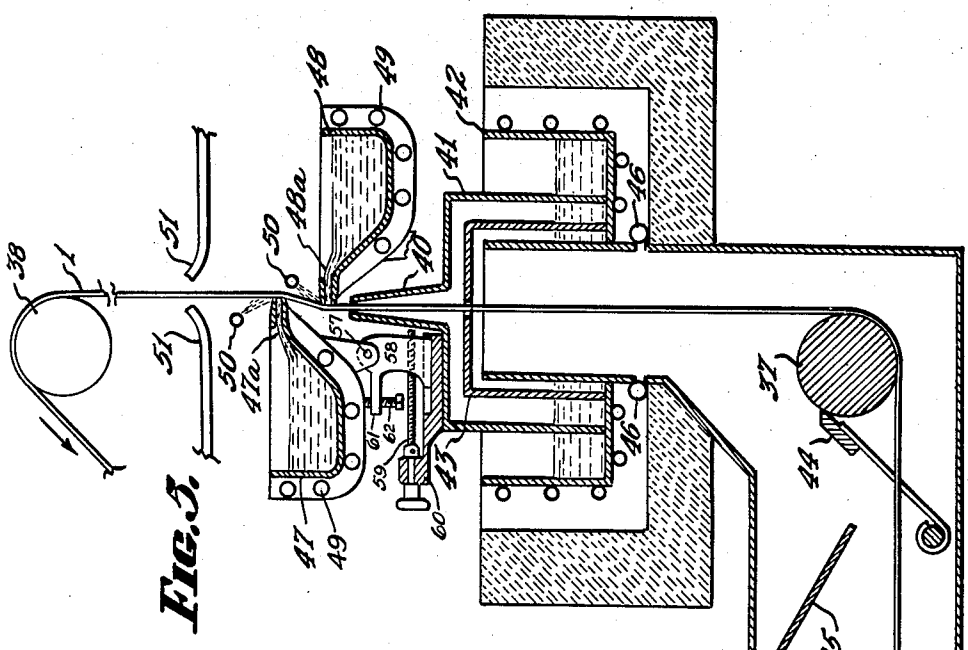


FIG. 3.

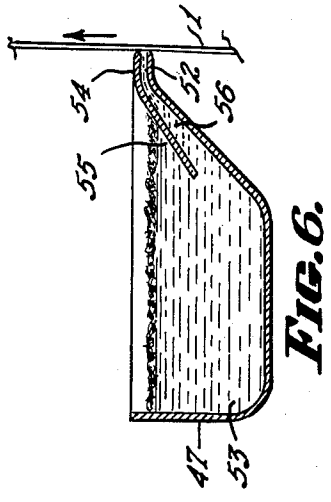


FIG. 6.

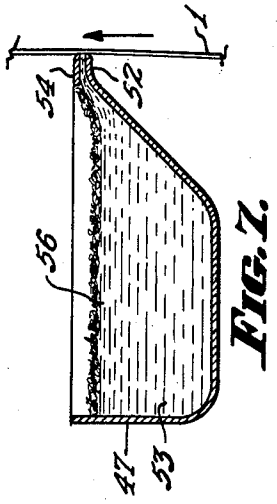
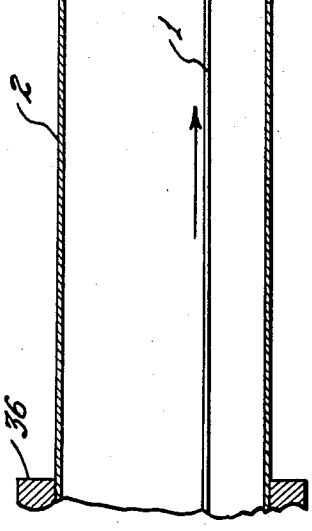


FIG. 7.



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United States Patent Office 2,914,419
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2,914,419

METHOD AND APPARATUS FOR CONTINUOUSLY COATING A METAL STRAND-LIKE ARTICLE WITH MOLTEN METAL

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Application August 3, 1953, Serial No. 372,073

29 Claims. (Cl. 117—7)

The invention relates to the continuous coating of metal bodies in endless lengths with molten metal. I shall describe the invention in exemplary embodiments involving the coating of iron or steel strip or wire with aluminum; but it will be understood that the invention is not so limited but is applicable to the coating of endless lengths of strip or wire of any metal with all of the molten coatings current in the art, such as zinc, zinc containing minor amounts of aluminum, tin, terne, alloys of aluminum and the like.

In the continuous hot coating of metal bodies, exemplary procedures in commercial use are described in the Sendzimir Patents 2,110,893, 2,136,957 and 2,197,622. In general, the scale-free strip or wire is cleaned as by the removal of oils, greases and the like, subjected to a heat treatment in a reducing atmosphere and carried beneath the surface of a bath of molten coating metal while still protected by the reducing atmosphere, so that no entrance flux need to employed. The metal to be coated is led into the coating bath at a temperature close to the temperature of the bath itself; and the surfaces of the metallic strand are thus prepared for very rapid and thorough wetting by the molten metal itself. In a specific though non-limiting procedure, iron or steel strip in scale-free, cold rolled condition is first carried through an oxidizing furnace wherein carbonaceous foreign matters are burned from the surface of the strip and an exceedingly thin, controlled coating of oxide is formed thereon. In the reducing furnace the thin oxide coating is reduced. Instead of the described treatment in an oxidizing furnace, alkali or other chemical cleaning involving wetting and drying of the strip surface may be practiced. Under certain operating conditions a cold-rolled strip can be cleaned sufficiently by merely passing it into the reducing furnace burning off the carbonaceous foreign matters in an initial section thereof; but pre-cleaning is preferred as a commercial procedure.

Procedures just referred to are desirable for preparing the surface of metallic strands for the reception of coatings of molten protective metal. As hitherto practiced, however, the coating step has involved a dipping procedure in which the metallic strands are passed through a bath of the molten coating metal with which they remain in contact for appreciable but short intervals. As a consequence, the molten coating metal rapidly becomes contaminated with the metal of the strands to be coated. For example, considerable quantities of dross will be formed in a zinc bath as well as in other baths of molten coating metal capable of dissolving iron; and in the case of aluminum or alloys rich in aluminum, the bath rapidly becomes saturated with iron if iron is the material of the strand to be coated. The presence of large quantities of iron in the molten aluminum is undesirable for several reasons. For example, coating with a bath presaturated with iron will make for less ductility and corrosion resistance in the coating, and gives rise to other difficulties.

The pick-up of iron by a bath of molten aluminum can occur from the pot in which the bath is maintained

and from guide, wiper and transfer-roll apparatus in the pot; but this action progresses relatively slowly. The contamination of molten aluminum occurs in by far the greater proportion and shorter time by solution of iron from the surfaces of the strip or strand which is carried through the pot. I believe this to be because of the extraordinarily ready solubility of the cleaned surfaces of the strand in the aluminum and also because of the comparatively great area of the strand surfaces exposed to the bath in a unit of time under conditions such that there can be an interflow between aluminum which has been brought against the strand and aluminum in the body of the bath. It is for this reason that previous attempts to minimize contamination of the bath by diminishing the size of the bath with respect to the quantity of material carried therefrom on the strand have not been successful. The contamination of the bath by iron from the strand and the dilution of the bath by addition of fresh uncontaminated metal result in the establishment of an equilibrium concentration of iron in the bath which may approach saturation if the immersion time is sufficiently long. Changing the size of the pot merely changes the time necessary for equilibrium to be reached. Much the same thing occurs with other coating metals where the base metal is soluble in them, or forms with them undesirable contaminants.

Other difficulties arise in withdrawing the strand from the bath of molten coating metal; and the problem of making thin, uniformly controlled coatings has never hitherto satisfactorily been solved. Obviously there is little control if the strand merely is withdrawn from the free surface of the bath; but the use of exit rolls (above the bite of which a meniscus of the molten coating metal collects) while an improvement, is not fully satisfactory. Attempts to scrape the surface of the strand after it has left the bath but before the coating metal has solidified are likely to result in removal of coating down to an interface alloy, which is undesirable. The problem is greatly complicated when the coating metal is one, like aluminum and its alloys, which readily forms tenacious surface oxide films promoting the formation of beads and ridges in the applied coating.

Yet again, the art has long desired a satisfactory mode of minimizing the production of interface alloys.

Primary objects of my invention are the provision of means and a method for forming thin, uniform and controlled coatings of good surface characteristics, for controlling the formation of interface alloys, and for increasing the purity of coatings of metal as applied in molten condition.

It is an object of one aspect of the invention to provide a mode of operation and a coating apparatus in which the amount of coating metal applied to the strand is the amount carried away by the strand, there being no reflux of applied metal to a bath, so that bath contamination is greatly reduced.

It is an object of this invention to provide a method of coating a strand of metal with a molten coating metal wherein it is possible to reduce the exposure of the strand to the molten coating metal to a sufficiently short time and to cool it so rapidly that the interfacial alloy or compound formed is limited to a thin, uniform layer which will not be deleterious to the adherence and ductility of the metallic coating.

It is a further object of this invention to provide a new aluminum coated ferrous product having superior coating adherence and ductility as well as improved corrosion resistance, the aluminum coating layer of which is attached to the base metal by a very thin, smooth and uniform interfacial alloy or compound layer, the aluminum layer itself being more uniform in thickness than has hitherto been possible.

Another object of the invention is the provision of a means and method whereby bath oxide is prevented from interfering with coating by being isolated from the metal increment which forms the actual coating.

Yet another object of this invention is the provision of means and a method for applying molten coating metal to a strand-like metal base in a controlled and uniform manner resulting directly in a controlled coating upon cooling.

These and other objects of the invention which will be set forth hereinafter or will be apparent to one skilled in the art upon reading these specifications, I accomplish by that procedure and in the use of that apparatus of which I shall now describe exemplary embodiments. Reference is made to the accompanying drawings wherein:

Figure 1 is a partial longitudinal section of a coating apparatus which I may use.

Figure 2 is a partial and semi-diagrammatic sectional view on a smaller scale showing the relation of the coating apparatus to a hood.

Figure 3 is a similar view showing a modified form of bath apparatus.

Figure 4 is a similar view showing yet another form of coating assembly.

Figure 5 is a longitudinal sectional view through a preferred apparatus used in practicing the invention.

Figure 6 is a sectional view through an applying device and strip showing an upper lip extension reaching the gravitational level of the molten metal in the applying device.

Figure 7 is an enlarged detailed view through the applying device of Figure 5.

Briefly, in the practice of one aspect of the invention I have found that it is practicable to apply molten coating metal to a metallic strand through the use of an applying device having a lip portion adjacent or contacting the strand, in such a way that a thin, uniform coating is produced in a controlled manner. The accomplishment of the function is dependent upon a plurality of factors as follows:

(1) A prerequisite for the application of a specific and controlled amount of the molten coating metal to strip material is that the lip element exert a uniform pressure against the passing strip across any face or area contacted by the lip. It must be kept in mind that the rolled base metal may not only have variations in thickness, both longitudinally and laterally due to rolling conditions, but also may be longitudinally and laterally curved. To take care of such variations and to flatten the strip for contact with lip elements, it has been found necessary to produce a deflection in the strip while it is moving under tension in the coating apparatus. The means producing the deflections may be the lip or the lips themselves, other elements located adjacent the lips, or a combination of the lips and such other elements.

(2) The lips should preferably be adjustable in such fashion as to vary the pressure and the amount of deflection because this enables the thickness of the coating to be regulated within limits.

(3) The molten metal contacts the strip on one side of the lip element (usually, though not necessarily, the lower side, the strip usually moving upwardly). The strip leaves the lip element at its other side (usually the upper side for the same reasons) in coated condition. Since the lip is pressed against the strip, the molten coating metal in the thickness desired must pass between the strip and the lip against the pressure aforesaid. This occurs presumably through a filming action of some sort, the strip being thoroughly wetted by the molten coating metal. The specific amount of coating metal which passes between the lip and the strip is in this instance dependent primarily upon the pressure of the lip against the strip. The deflection of the strip by the pressure of the lip will produce the greatest flattening effect and result in the greatest uniformity of coating the more nearly the edge of the lip approaches a line contact with the strip. Optimum results are obtained by a very narrow flat lip edge with the plane of the flat area substantially parallel to the strip.

(4) If more of the molten metal passes between the strip and the lip than can be carried away by the strip, it will tend to collect at the other side of the lip in a meniscus or even to overflow the lip. This can in part be controlled by varying the pressure as aforesaid; but another and important element of control is to be found in operating under what I have herein termed "negative pressure." In the apparatus hereinafter described the lip elements are arranged to contact the strip along lines above the gravitational top level of the molten metal in the coating bath. The molten metal is drawn up into the space between the line of contact of the lip and the top level of the bath, by the filming action aforesaid, by capillarity or surface tension effects or otherwise so that the hydrostatic pressure of the molten metal against the lip is less than it would be under conditions in which a gravitational head were added. This is what I mean by the term negative pressure as used herein and in the claims which follow. I have found that the thickness of the coating produced is inversely affected by the amount of negative head and furnishes another important means of control.

The collection of molten metal at the free side of the lip element is to be avoided since it will make for nonuniformity of coating, and will also make for beading and ridging where coating is being done with a metal like aluminum which rapidly forms tenacious oxide films.

The fundamental teachings of this application are not limited to the coating of strip. In the coating, for example, of drawn wire, where variations in thickness, curvature, camber and the like are not apt to be encountered, and where the material may be accurately guided, it will not ordinarily be necessary to provide for a deflection of the strand by the lip elements. Furthermore, the lip structure may be redesigned to form a single element surrounding the wire, the wire passing through a perforation in it. I shall, however, describe my invention in connection with exemplary embodiments which have to do with the coating of strip. By strip I mean rolled metallic bodies of indefinite length, usually though not necessarily of sheet thickness, and varying in width from relatively narrow strip in which, however, the width is a plurality of times the thickness, to strip of width sufficient for the formation of coated metal sheets of any commercial dimensions.

Under proper circumstances I have found it possible to form thin, uniform and completely controlled coatings of molten metal on base metal strip without the collection of excess on the free side of the lip, and with no irregularities due to the formation of excess oxide film, the strip carrying away with it all the molten coating metal which passes between the strip and the lip.

Translated into terms of apparatus, the teachings above may take the form shown in any of Figures 1 to 4 inclusive.

The preparation of the metallic surfaces of the strand-like material to be coated, e.g. ferrous strip or wire, is of primary importance in my process, as it is in any continuous coating procedure. The conditions contemplated in the reducing furnace and the subsequent cooling hood are the same as those set forth in the patents referred to above. It may be pointed out that the strip will be raised in the reducing furnace to temperatures at which a strong reducing effect will be obtained; but for special effects, such as annealing, normalizing, or softening by the method of the copending application of Robert S. Burns and Robert L. Solter, Serial No. 30,856, filed June 3, 1948, now Patent No. 2,656,285, issued Oct. 20, 1953, and entitled Production of Soft Iron

and Steel Sheet Stock, the temperature may be raised to whatever value is desired.

A cooling hood is employed to lower the temperature of the strand to a value not far from that of the melting point of the coating metal and preferably but not necessarily below it, to facilitate the rapid cooling after coating. For example, in coating with pure aluminum, which has a melting point of about 1215° F., I may have the strip at about 1150° F. and the molten aluminum at about 1350° F. It is desirable to adjust the temperature of the strand and of the coating metal to such a relationship that complete wetting is obtained with the lowest possible heat content of the composite mass. Particularly in coating heavier gages, beneficial results are obtained if the entering strip temperature is as low as around 950–1000° F., and to get rapid wetting the molten aluminum is raised considerably above its melting point even to as high as 1400 or 1450° F.

Referring first to Figure 2, I have shown in a diagrammatic fashion a strip **1** passing through a cooling hood **2** and into a bath of molten metal **3** in a vessel **4**, through a bell **5** which dips beneath the surface of the molten coating metal and therefore protects the strip **1** from oxidation. As shown in Figure 1 the edged lips or pressure members **6** and **7** are displaced vertically with respect to each other and exert pressure against the strip **1** so as to deflect it in its vertical travel. In the particular embodiment illustrated the strip is tensioned between a lower roll **8** and an upper roll **9**, as will be evident in Figure 2.

In order to provide for the elements of control discussed above, the lip elements **6** and **7** are mounted in the way next described. Base plates **10** and **11** are mounted in opposite pairs on the sides of the molten metal containers **4** or on independent foundations. Supporting elements **12** and **13** are mounted for horizontal sliding movement toward and away from the strip **1** on the base plates **10** and **11**, their positions being adjustable by means of screws **14** and **15**. The supporting elements have overhanging portions **12***a* and **13***a*; and brackets **16** and **17** are mounted so as to be vertically slidable on dowels **18** and **19** on the supports. The vertical positions of the brackets **16** and **17** are made adjustable by means of screws **20** and **21**.

Shafts **22** and **23** extend across between respective pairs of the brackets **16** and **17**, and the lip elements **6** and **7** are mounted on these shafts by means of arms **24** and **25**, as many of which may be provided as required for stiffness. The angular positions of the lip elements **6** and **7** may be adjusted by turning the shafts **22** and **23** or by adjusting the positions of the arms **24** and **25** on the shafts if the shafts are fixed, as indicated in Figure 1. The tips of the lip elements, indicated at **6***a* and **7***a*, may be made of special metal of non-wearing characteristics such for example as molybdenum; the trips are edged as shown. They contact the strip **1** along lines vertically above the gravitational top level of the bath **3**. This top level is indicated at **26**. Due to the action explained above, the molten metal will be drawn up into the spaces **27** and **28** above the top level of the bath. The lip elements **6** and **7** will keep any film of oxide forming on the top surface of the bath away from the strip **1**. The strip is shown as deflected or bent where it passes between the tips **6***a* and **7***a* of the lip elements for reasons already given. The drawings are dimensionally exaggerated for clarity.

The described mechanism permits control of the weight and thickness of the coating in a desired range irrespective of variations in gage, speed, and tension of the coated strip. For example, with a given speed and tension of the strip an increased weight of coating may be attained either by lowering the lip members toward the normal bath surface, or by decreasing the pressure of the lip tips against the strip and the consequent degree of deflection, providing sufficient deflection is maintained to flatten the strip. Differential adjustment of the coating on the two sides of the strip is also possible. For example, in order to decrease the weight of coating on one side of the strip the pressure of the lip on that side may be increased by moving the lip toward the strip and increasing the deflection produced by it. At the same time the lip element on the opposite side of the strip may be moved slightly back so that the weight of the coating formed on the second side is not changed.

The adjustment of the height of the lips above the free bath surface, and the adjustment of their pressure against the strand, permit a wide range of weights of coating for a wide range of gages to be attained. For heavier gages the vertical displacement between the tips of the lip elements may be somewhat increased so that excessive pressures are not necessary in order to obtain straight line contact of the lips with the strip.

In Figure 3 I have shown a shallow and relatively small vessel **29** for the molten metal supported directly on an upturned portion **30** of the cooling hood **2**. The strip **1** enters the molten coating bath **3** through an orifice in the bottom of the vessel **29**, so closely dimensioned to the strip **1** or provided with suitable seals so that the molten metal will not drain down into the hood. Here the length of the path of travel of the strip through the molten metal may be greatly diminished and the volume of the molten metal in the vessel **29** greatly cut down.

A modified form of apparatus is illustrated in Figure 4 where a pan **31** is affixed to the hood, the upward extension **30** of the hood opening through the pan. The vessel **32** for the molten coating bath is provided with floats **33** and **34** so that it may be supported upon a molten lead bath **35** in the pan **31**. The strip **1** again enters the vessel **32** through a slot in the bottom of it; and the path of travel of the strip through the molten coating metal is very short. In both Figures 3 and 4 the lip elements are again indicated at **6** and **7**.

I have described above means and an operating procedure resulting in the imposition of thin controlled coatings of molten metal. In some embodiments the length of time of contact between the prepared surface of the strand and the bath of molten coating metal is minimized. The growth of an interface alloy layer between the base metal and the coating metal is largely a function of the time of contact between the two metals when one of them is molten. But inasmuch as the growth of an alloy layer with many metals, such particularly as aluminum, is very rapid, and inasmuch as the interface alloy layer continues to grow after the coated strand has left a molten coating bath during a period of time when the coating metal is liquid, it will be seen that a rapid cooling of the coated strand may become as important as a short immersion time and that optimum results will be obtained if both are reduced to an absolute minimum. I shall now describe apparatus and a method of procedure for accomplishing this, utilizing principles set forth above in combination with other factors.

It should be pointed out that the finishing of the coating is of great importance in minimizing contact time. If the coating is relatively thick or is irregular in thickness, the coated strand cannot be as rapidly and uniformly cooled as otherwise. Yet again, the use of conventional coating pots and exit apparatus such as exit rolls interfere with the use of means for rapidly cooling the coated material. In the practice of my invention in its preferred form, the provision of means operating on the principles set forth above for forming thin, uniform and controlled coatings permits the concurrent adoption of practices which reduce the time of contact between the base metal and the coating when molten to very short intervals. In practice, I am producing materials in which the total time of contact between dissimilar metals when one of them is molten is below two seconds.

I am also enabled through a combination of factors

to employ a coating method in which the molten coating metal is applied to the strand only in such quantities as can be carried away by the strand, so that there is no reflux of molten coating metal between the surfaces of the strand and a reservoir or bath of the molten coating metal. Under these circumstances the supply of molten coating metal does not become appreciably contaminated with metal dissolved from the strand, and the coated strip can be cooled so quickly as to result in an alloy layer of controlled thickness.

Figure 5 shows a preferred form of apparatus which I have developed to limit the contact of the base metal with the coating metal while it is in the molten condition to as short a time as possible to limit the amount of alloying while still producing a uniform and controlled weight of coating.

In Figure 5 I have not illustrated the portions of the Sendzimir apparatus lying in advance of the cooling hood. The strip **1** is shown as passing through the cooling hood **2** which may be regarded as attached to the Sendzimir reducing furnace by means of the flange **36**. The strip passes beneath a roll **37** inside the hood and exits vertically to a drive roll **38** or other suitable propulsion and tensioning apparatus located beyond the coating point.

The strip or strand emerges from the hood vertically through a slot or nozzle element **40** which is accurately positioned in an exit piece **41**. The lower end of the exit piece is located in a trough or basin-like element **42**, through which the upper part of the gas-tight hood **2** extends and to which it is welded. The basin **42** is filled with molten lead to effect a gas-tight seal between the hood and the exit piece **41**. It will be provided with electric or other heating elements to keep the lead in molten condition, and will further be provided with an insulative casing as shown.

An inner cover member **43** with an opening for the passage of the strand is employed to restrict the escape of gas from the hood during threading or at such other times as it is found necessary to remove the exit piece **41** when the hood is filled with reducing gas. The inner cover **43** is removable and is sealed in the same way as the exit piece **41**. The opening in the upper end or exit part of the hood should be large enough to permit the removal of the roll **37**, its bearings and preferably a scraper **44**. The scraper is employed on the roll **37** to keep the surface thereof smooth and free of scale particles or other accumulations which might make indentations in the hot strip passing around the roll under tension. It will be understood that while normally the strip **1** will be perfectly clean as it reaches the roll **37**, provision must be made for the removal of scale and the like from the hood and apparatus during periods of starting up, when an oxided strip may be passing through the apparatus before the atmosphere in the reducing furnace has attained a proper reducing activity.

A plate **45** may be welded at an angle inside the hood to deflect the strip **1** under the roll **37** during threading operations.

I locate pipes **46** on either side of the upper extension of the hood **2** and opening to the interior of the hood. The pipes may be welded to the hood proper with a slot or slots in each pipe coinciding with slots in the hood wall. They are employed to feed vaporized sodium into the inside of the hood **2**. Sodium is vaporized preferably at about 1075° F. in a separate furnace or retort and is carried to the hood through the pipes **46** by dissociated ammonia gas or other reducing gas employed in the hood. The vaporized sodium is employed to control the reaction product between aluminum and the reducing gas atmosphere, so that a coating can be applied to the strand which is continuous and free from non-wetted areas, in accordance with the teachings of Patent 2,437,919 in the name of Oganowski. In the case of coating with other molten metals, the vaporized sodium is frequently used for scavenging the reducing atmosphere within the hood and furnace.

The mode of applying the molten metal to the strand, as hereinafter described, may be practiced entirely within the hood **2**. I do not prefer to do so because the applicators then become inaccessible or less readily accessible for purposes of adjusting, cleaning and the like, and more difficulty is had with the rapid cooling of the strip. I have found it entirely possible to coat the metallic strand **1**, outside the hood **2**, by apparatus illustrated in the drawings hereof. Precautions must be taken, as hereinafter described to protect the surfaces of the strand up to the coating point.

Containers for the molten coating metal (aluminum in the exemplary embodiment) are indicated at **47** and **48**, and are hereinafter referred to as applicators. They are located on either side of the strand above the nozzle **40** of the exit piece **41**. Electric or other heaters **49** are attached to these applicators to provide sufficient controlled heat either for melting the aluminum or for holding it in molten condition depending upon the method of charging the aluminum or other coating metal into the applicators. It is within the scope of the invention to melt the aluminum or other coating metal in a separate furnace or ladle and to convey it to the applicators **47** and **48**, preferably by conduit means having an automatic valve control for maintaining a desired level of the molten coating metal in the applicators. Each applicator has a mouth indicated at **47***a* and **48***a* in Figure 5, through which the molten coating metal is fed or siphoned to the surfaces of the strand **1** in ways hereinafter explained.

In Figure 5 in connection with the vessel **47** a diagrammatic showing has been made of means whereby the vessel may be tilted and whereby it may be adjusted toward and away from the strip **1**. Thus the vessel is indicated as pivoted at **57** to a nut **58** riding on a threaded shaft **59** which is journaled into a support **60** on a base. Movement of the threaded shaft **59** will carry the vessel toward and away from the strip. The nut **58** has an extension **61** with a shaft **62** threaded therein and engaging the vessel at a point spaced from the pivot point **57**. Adjustment of the threaded shaft **62** will produce a tilting of the vessel about the pivot in either direction.

In the particular apparatus shown, where the coating of the strip occurs outside the hood, it is important that reducing gas from the hood flow through the nozzle **40** about the strand or strands and that its flow be so adjusted that the strand-like material is completely enveloped by the reducing atmosphere up to the point at which it is contacted by the molten coating metal. The spacing of the coating portions of the applicators **47** and **48** from the end of the nozzle element **40** may depend on variables such as the strip gage and tension, the degree of strip deflection required to attain the desired lip pressure, and the amount of reducing gas issuing from the nozzle. In all cases it is necessary to have them close enough to the end of the nozzle to preserve a non-oxidized condition of the strand surface until the coating is applied. Dry, oxygen-free reducing gas, such as hydrogen or dissociated ammonia, from a source outside the hood can be fed into the space between the applicators and the nozzle for additional surface protection if desired. I have found that in the particular apparatus employed by me, it is readily possible to protect the strip by means of gas issuing from the hood if the coating portions of the applicators are located not much more than about 1½ in. above the end of the nozzle **40**.

Gas finishing pipes **50** may be located immediately above the coating portions of the applicators. A protective gas is delivered through these pipes and is fed from them through perforations extending across the length of the coating portions. Preferably the pipes are supported by means providing precise adjustment in all planes, and the gas is preferably directed at the contact

point between the strand and the coating portions of the applicators. The function of the finishing gas is to control the rate of oxide formation on the molten coating metal as it is carried away by the issuing strand. Natural gas has been used most effectively as a gas finishing atmosphere, although other non-oxidizing gases may be employed. It is not certain just how the finishing gas operates, but using the gas finish, I have had no difficulty in aluminum coating without the breaking of oxide films and the formation of "tear drops."

It will be understood that the reducing gas issuing through the nozzle 40 from the hood 2 as well as the gas used for gas finishing issuing through the pipes 50, is preferably burning.

Upwardly directed scoops 51 are located on both sides of the strand immediately above the applicators 47 and 48, and conduct low pressure air at or below room temperature to the surface of the strand in large volume to freeze thereon the coating as fast as possible. As one skilled in the art will readily understand, the number of scoops required will vary with the gage and speed of the strand, with the temperature of the air, with its volume and the like, and these factors may be controlled to produce the desired rate of cooling. Other cooling means, such as compressed air applied through perforated pipes may be used, as well as steam sprays, water sprays, and water cooled rolls alone or in combination. If the bottom angle of contact between the cooling air and the strip be not greater than about 30°, there will be no interference with the gas finishing even though the air scoops are located, as shown, quite close to the pipes 50.

As has already been pointed out, the purpose of rapid cooling has to do with the control of the alloy layer. Previous attempts to limit the thickness of the alloy layer in aluminum coating steel strips primarily have taken the direction of adding certain elements to the aluminum bath which suppress alloy formation, such as silicon or beryllium. They have not been completely satisfactory. The addition of alloying elements to the coating bath has lowered the ductility of the coating, decreased its corrosion resistance, and in the case of beryllium, presented a health hazard.

Below the freezing point of aluminum, the rate of alloy formation is sufficiently slow to have a negligible effect on adherence provided the strip is cooled to less than 500° F. within a reasonable length of time, roughly not more than about a minute and a half. In my process the total time of contact between the strand and the molten metal is cut to the absolute minimum, as hereinafter explained. Under the conditions described there will always be an interface alloy layer sufficient for good bond, because aluminum reacts almost instantaneously with a steel strip surface which has been thoroughly cleaned and is at a temperature suitable for complete wetting.

The precise way in which aluminum alloys with iron is not completely understood. Apparently one or more iron-aluminum alloys of definite composition are formed at the interface between the base metal and the coating. The instant formation of these alloys is capable of robbing the coating metal of some of its iron content if it is initially contaminated with iron, as indicated by the fact that in quick frozen coatings produced in ways hitherto current in the art, an analysis of the overlying aluminum will show somewhat less iron in the outer layers than the content of iron in the bath itself. But the formation of the interface alloy will not itself purify the overlying aluminum in a quick frozen coating; and to the extent that the applied aluminum initially contains dissolved iron, the coating is likely to be less ductile and less adherent, and the quantity of interface alloy is likely to be greater. It has hitherto been recognized that while some interface alloy is necessary for adhesion, the qualities of the coated product are greatly impaired if the interface alloy becomes too thick.

Using the new method and apparatus, I have been able to reduce the length of time the strip is in contact with molten aluminum so that the alloy is controlled to a very thin, smooth, uniform layer without the use of alloying additions to the coating metal. This has made it possible for the first time to produce an aluminum coating of uniform and controlled thickness on iron or steel by a continuous process without the use of alloying ingredients which will simultaneously have excellent ductility, adherence and corrosion resistance.

I have already indicated that in ordinary coating processes the pick-up of iron in the molten coating metal in the coating pot is largely due to solution of iron from the strand itself. Solution of iron from the pot and its appurtenances is much slower and theoretically could be minimized or overcome for a given rate of replenishment by diminishing the relative size of the molten bath. In the process of the preferred aspect of this invention solution or iron from the strand into a resident bath of the molten coating metal is prevented. Thus, making the applicators small in volumetric capacity in relation to the quantity of aluminum passing through them will be effective in greatly minimizing solution of iron into the aluminum from the applicators themselves. However, it is within the scope of my invention to make the applicators of non-contaminating material such, for example, as of ceramics or of metals or alloys which do not dissolve readily in molten aluminum. There are various alloys having such property, and I may use any of them. By way of example, molybdenum or alloys high in molybdenum may be used.

The coating portions or mouths of the applicators are provided with a pair of lips. Referring now to Figure 6, I have shown one form of construction in which the lower lip 52 forms an extension of one edge of the applicator 47. It will be noted that the lip proper in this figure is shown as lying substantially above the level of the molten coating metal 53 in the applicator. The upper lip, indicated at 54, is provided with an extension 55 carried downwardly to a position below the top level of the molten coating metal. Assuming that the applicator is one designed for coating strip, the lip elements will be elongated in the direction of the transverse dimension of the strip 1 as much as may be necessary to coat its width, and the upper lip element 54 and its extension 55 may be thought of as fastened or welded to the end portions of the applicator 47. There is thus a channel indicated at 56 between the lower lip and the upper lip and its extension, this channel forming a sort of spout extending in the figure above the top level of the body of molten coating metal in the applicator 47. The uncoated strip rides against the outer surface of the lower lip 52 and the coated strip against the outer surface of the upper lip 54; and by reference to Figure 5, it can be seen that the strip may be confined between the lips of the opposite applicators 47 and 48, so as to be deflected thereby, and so that these lips, acting together, guide and flatten the strip in such manner that the applicators remain in contact with it at all times.

In Figures 5, 6 and 7 the lips are dimensionally exaggerated for the sake of clarity. In the present practice of my process the contacting portion of each lip is about $\frac{1}{16}$ of an inch wide and the upper and lower lips are spaced from each other a distance of $\frac{1}{10}$ of an inch. The total effective thickness of the two lips and the space between them is .225 inch. These dimensions are illustrative only. It will be understood that the contacting portions of the lips may be reduced portions of metallic elements which are of substantially greater thickness for strength, the elements being beveled or tapered to provide contacting portions of the desired thickness.

The upper and lower lips preferably terminate toward the strip in a single plane. The applicators are arranged so as to have adjusting movement toward and away from each other so as to secure the desired deflection of the

strip and the proper line contact of the lips therewith. The applicators have adjusting tilting movements so as to bring both the upper and lower lips into the proper contact with the slightly deflected strip.

The spout may be filled by temporarily raising the level of the molten metal in the applicator until it fills the spout and contacts the strip between the upper and lower lips. Mechanical adjustments are provided for the precise positioning of the applicators. These include means for tilting the applicator as well as means for adjusting it in the horizontal and in the vertical planes, as has been indicated.

It will be understood that the surfaces of the metal strip 1 have been prepared in such a way and are at such a temperature as to be very readily wet by the molten metal in the applicator 47. It will be understood that the strip is moving in the direction of the arrow and that the width of the orifice formed between the two lips is so narrow that any metal applied to the strand will be carried away from the applicator by the strand.

In order to control to the best effect the application of the metal to the strand thinly and uniformly, I have found it advisable to operate under conditions of negative gravitational pressure, as explained above. I have indicated that the metal level in the applicator is raised until the metal is brought against the surface of the strand. When this has happened, however, and when the surface of the strand has been wetted by the molten metal, I lower the metal level in the open portion of the applicator so as to bring the orifice between the two lips again above the gravitational top level of the molten metal in the applicator. The molten metal, however, continues to fill the passageway 56 and to flow through this passageway to the surface of the strip, and it continues to be carried away thereby.

A simplified form of applicator is shown in Figure 7. Here the upper lip element 54 is provided wholly located above the gravitational top level of the molten metal in the applicator, but there is no lip extension corresponding to the element 55 of Figure 6. Instead, reliance is had upon a film of oxide 56 which forms on the surface of the bath and connects the gravitational surface of the bath with the lip member 54. The lip member 54, however, keeps this oxide film from contact with the coating formed upon the strand, so that no oxide is carried out of the bath onto the strand and the only oxide formed upon the surface of the strand is that controlled by the finishing gas issuing from pipes 50, as previously explained.

The lips 52 and 54 may be made from a material which possesses resistance to attack from the molten coating metal. Where aluminum is the coating substance, the material of these lips should preferably be wettable by molten aluminum, but should not alloy too rapidly with aluminum since otherwise it will erode away excessively and require frequent replacement. Also, the material should have good wear resistance as well as a low coefficient of friction with the strand itself, so that the coating can be applied uniformly and without any galling between the strand and the lips. When coating iron or steel with molten aluminum (and this is inclusive of all coating alloys containing aluminum as a major ingredient) molybdenum and cast iron are examples of materials which can be used to make the coating lips. The contour of the coating lips should be precise so as, for example, to maintain the same relationship between the lips and between the lips and the strand, all across the area of the strand which is being coated by the applicator. While I have shown opposed applicators for simultaneously coating both sides of a strip, it will be evident that my apparatus is useful in instances where only one side of a strip need be coated, where a single applicator only is used, and where the strand is held against the applicator lips by a suitable substitute guide and deflecting means on the opposite side. Also, it is within the purview of the invention to coat opposite sides of a strip with different coating metals, as will be evident.

The aspects of control in the formation of thin, uniform coatings with the apparatus of Figures 5 to 7 inclusive are essentially similar to those discussed in connection with Figures 1 to 4 above. It is essential that the upper lip of each applicator be pressed against the surface of the strand and that the strand be deflected sufficiently to bring about uniform line contact under substantially uniform pressure between the strand and the lip. Pressure and the degree of deflection can be varied by moving the applicators toward and away from the strip. The applicators will normally be displaced one from another vertically. Thickness of coating can be adjusted as before by control of pressure and by control of the amount of negative head. The upper lip of the applicators will be preferably configured and edged such that the strip contacting surface is not thicker than 1/8 inch and will generally give best results when around 1/16 inch thick or less. It is also in the purview of the invention to provide for a tilting of the upper lip with respect to its applicator.

Modifications may be made in the invention without departing from the spirit of it. Having thus described the invention in certain exemplary embodiments, what I claim as new and desire to secure by Letters Patent is:

1. A process of continuously coating a metal strand-like article with molten coating metal which comprises cleaning the strand-like article, and while the article is in the cleaned condition, moving said article past a member having a lip against which the article moves, contacting the article with molten coating metal at the approach side only of said lip, said molten coating metal being derived from a source thereof, said source having a top gravitational level which is located below the level of said lip, the movement of the article acting to carry a thin film of the molten coating metal between said article and said lip, maintaining said molten coating metal at the approach side of said lip in continuous contact with the metal in said source so as to form a continuous body of the molten coating metal extending from said top gravitational level of said source upwardly to said lip, the surface of said body located away from said article being an unbroken upward extension of the surface of the metal in said source at said gravitational level, and isolated from air at said surface, the weight of said body of molten coating metal being opposed to the passage of said molten coating metal between said lip and said article, and said member having a portion adjacent said lip, which portion is so located as to contact any film of oxide floating on the said source of molten coating metal to keep said film from contacting said article.

2. The process claimed in claim 1 wherein the strand-like article is a strip, in which the lip member is an elongated element and in which the lip member is pressed against the strip in such fashion as to deflect it, the strip being tensioned in its passage past the lip member.

3. The process claimed in claim 2 wherein the lip member has a definite edge and in which the amount of molten coating metal passing between the strip and the lip member is controlled in part at least by varying the pressure between the strip and an adjacent portion of the lip member.

4. The process claimed in claim 3 in which the strip is coated on both sides through the use of two lip members offset from each other in the direction of motion of the strip and each producing an opposite deflection therein.

5. The process claimed in claim 4 wherein each lip member is a part of an applicator having a second lip member closely adjacent to but spaced from the first mentioned lip member, the molten coating metal being confined between the lip members of each applicator.

6. The process claimed in claim 5 in which the coated

strip is rapidly cooled immediately beyond said first mentioned lips.

7. A process of continuously coating a strand-like article with molten coating metal which comprises cleaning the strand-like article and while the article is in the cleaned condition, applying the molten coating metal thereto from a source while the strand-like article is in motion, the application of the molten coating metal being confined by lip elements contacting the same side of said article and spaced from each other by a distance so short in the direction of motion of said strand-like article that the molten coating metal applied thereto is carried away thereby without opportunity for reflux to said source, the said molten coating metal at the point of application being higher than the gravitational level of the molten metal in said source.

8. A process of coating a moving strand-like metal article with molten coating metal which comprises thoroughly cleaning the said strand-like article and heating it, providing a source of molten coating metal, applying said molten coating metal to the strand-like article at a position above the gravitational top level of the molten coating metal in said source, by providing a passageway between the said source and the point of application of said molten metal, which passageway is characterized by lips spaced in the direction of motion of said article, said passageway being closed to the external atmosphere and causing the withdrawal of the molten coating metal from said point of application and the end of said passageway by the said strand-like article moving in contact with said lips to produce a flow of the said molten metal therethrough.

9. The process claimed in claim 8 wherein said source of molten coating metal is a pan-like container, one of said lips forming an edge of said container, and the other of said lips, spaced from the first mentioned lip in the direction of motion of said article, having an extension passing downwardly into said molten coating metal in said pan-like container below the top gravitational level thereof, said extension, said lips and adjacent walls of said container forming a closed passageway from the body of said molten coating metal to said strand-like article, through which passageway the molten coating metal is drawn under negative pressure.

10. The process claimed in claim 9 wherein the said strand-like article is in the form of strip and wherein a second similar pan-like container is located on the side of the strip opposite the first mentioned container, the strip being guided and deflected by the lips of the first mentioned container and the lips of the second mentioned container, whereby the lips of said containers maintain line contact with said article.

11. The process claimed in claim 9 wherein the said strand-like article is in the form of strip and wherein a second similar pan-like container is located on the side of the strip opposite the first mentioned container, the strip being guided and deflected by the lips of the first mentioned container and the lips of the second mentioned container, and wherein said strip immediately after coating is surrounded by a non-oxidizing atmosphere.

12. The process claimed in claim 9 wherein the said strand-like article is in the form of strip and wherein a second similar pan-like container is located on the side of the strip opposite the first mentioned container, the strip being guided and deflected by the lips of the first mentioned container and the lips of the second mentioned container, and wherein said strip immediately after coating is surrounded by a non-oxidizing atmosphere, and is thereafter rapidly cooled.

13. The process claimed in claim 8 wherein the molten coating metal is applied to the said strand-like article in a transverse area so short in the direction of motion of the said strand-like article as to enforce a flow of the said molten metal through said passageway in the one direction only.

14. The process claimed in claim 13 wherein the strand-like article immediately after coating is surrounded by a non-oxidizing atmosphere.

15. A process of coating a moving strand-like metal article with molten coating metal which comprises thoroughly cleaning said strand-like article and raising its temperature, providing a pan-like container having leading and trailing spaced lips, maintaining a bath of molten coating metal in said pan-like container, moving said strand-like article past and in contact with said lips, causing said molten coating metal to flow by gravity and contact said article between said lips whereby to coat it, and while said article is in a state of continuous motion, bringing the gravitational upper level of the molten coating metal in said container to a position below the level of the said lips, during a continuation of the aforesaid coating, whereby said molten coating metal is caused to travel upwardly along a portion of said container to the trailing lip.

16. The process claimed in claim 15 wherein the said strand-like article is in the form of strip and wherein a second pan-like container is located on the side of the strip opposite the first mentioned container, the strip being guided and deflected by the lips of the first mentioned container and the lips of the second mentioned container, and wherein said strip immediately after coating is surrounded by a non-oxidizing atmosphere, the said strip being surrounded by a non-oxidizing atmosphere from the point at which it is cleaned to the point at which it is coated.

17. In coating apparatus for coating a strip with molten metal, means for moving a strip in a path, a source of molten coating metal, the said metal therein having a gravitational upper level, a lip member having an approach and withdrawal side with respect to said moving strip, means for pressing said lip member against said strip so as to deflect it from said path, and means for bringing against said strip a quantity of molten metal on the approach side only of said lip member whereby a film of molten coating metal formed on the surface of said strip is carried between said strip and said lip member against said pressure, the said molten metal on the said approach side of said lip member being higher than said gravitational upper level, said lip member having a portion spaced from said strip and extending downwardly below said gravitational upper level whereby to enclose a continuous body of the molten metal extending above said gravitational upper level, the weight of which body is opposed to the passage of the molten coating metal between said strip and said lip member.

18. Apparatus as claimed in claim 17 including means for adjusting the relationship between said lip member and said strip.

19. Apparatus as claimed in claim 17 including a second lip element in close proximity to the first, the said molten metal as applied to said strand being initially confined between said lip elements to so narrower an area in the direction of motion of said strand as to enforce flow of molten metal in one direction only.

20. Apparatus as claimed in claim 17 including means for adjusting said lip member toward and away from said strip whereby to vary said pressure.

21. Apparatus as claimed in claim 20 including means on the opposite side of said strip and offset from said lip member in the direction of strip movement, said means and said lip member acting to deflect said strip and maintain line contact between said lip member and said strip.

22. In coating apparatus a vessel for holding a quantity of molten coating metal, means for passing a strip through molten coating metal in said vessel, a lip mem-

ber of elongated form adjacent a face of said strip and mounted with respect to said vessel so that the edge of said lip member adjacent said strip is above the gravitational level of the molten metal in said vessel, while the opposite edge is therebelow, means for adjusting said lip member toward and away from said strip, means for tilting said lip member, and abutment means located on the opposite side of said strip, for holding said strip against said lip member.

23. The structure claimed in claim 22 in which said abutment means is another similar but oppositely directed lip member, longitudinally displaced from said first lip member and having a similar adjustability and relationship to the molten metal in a vessel.

24. In apparatus for coating a metal strip with molten metal, a vessel adapted to contain a bath of molten metal, said vessel having at one side a pair of closely spaced lips, the space between said lips being open to the interior of said vessel, means for moving a cleaned metal strip in a path outside said vessel but so located as to bring said strip in contact with said lips, and means for varying the gravitational level of a bath of molten metal within said vessel so as to cause said molten metal first to pass gravitationally between said lips to contact said strip and thereafter to pass upwardly against the force of gravity over one of said lips so as to continue to contact and coat the said strip, the said lips being located so close together as to define a body of the molten coating metal which will remain continuous and unbroken in its extent above the gravitational upper level of said bath so long as said moving strip remains in contact with said lip, the other said lip acting to contact any film of oxide floating on said bath to keep said film from contacting said strip.

25. The structure claimed in claim 24 wherein the means for varying said upper gravitational level of said bath is a tiltable mounting means for said vessel.

26. The structure claimed in claim 25 in combination with means for cleaning the strip including means to raise its temperature and hood means to surround it with a non-oxidizing atmosphere, the said vessel being located beyond the termination of said hood means and means for bathing said strip in a non-oxidizing atmosphere from the termination of said hood means to the point at which said strip contacts said lips.

27. The structure claimed in claim 25 wherein a second similar vessel is positioned on the opposite side of said article and said article is confined, guided and deflected by the lips of the said vessels.

28. The structure claimed in claim 25 wherein a second similar vessel is positioned on the opposite side of said article and said article is confined, guided and deflected by the lips of the said vessels, and including means for surrounding the said article with a protective non-oxidizing atmosphere for a portion of its travel immediately beyond the said vessels.

29. The structure claimed in claim 25 wherein a second similar vessel is positioned on the opposite side of said article and said article is confined, guided and deflected by the lips of the said vessels, including means for surrounding the said article with a protective non-oxidizing atmosphere for a portion of its travel immediately beyond the said vessels, and including means for delivering a cooling fluid against the said article immediately after it has been coated.

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