July 8, 1969 J. F. CLARKE ET AL 3,453,849

MANUFACTURE OF CLAD METALS

Filed Oct. 13, 1965 Sheet 1 of 2

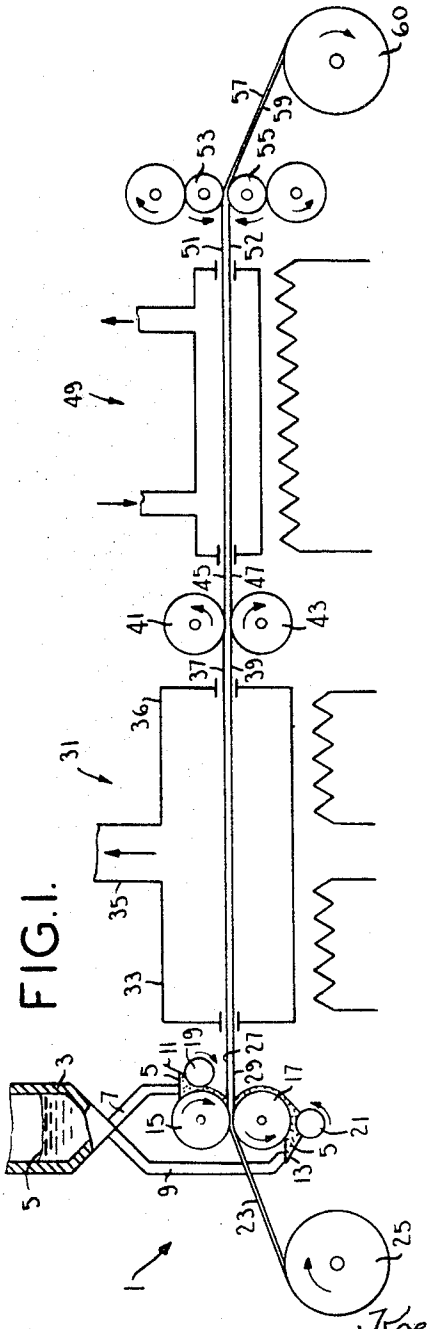


FIG. 1.

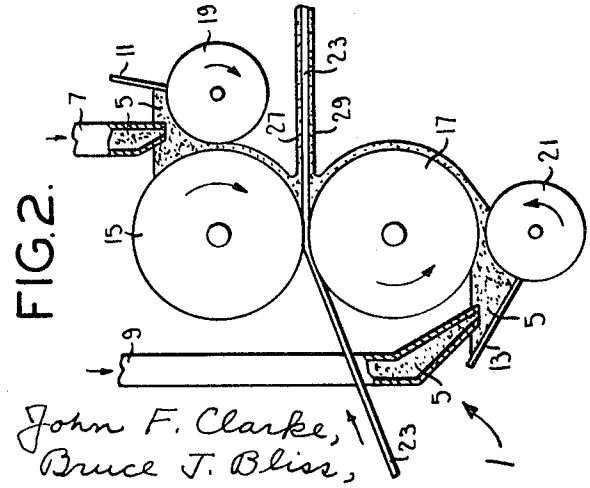


FIG. 2.

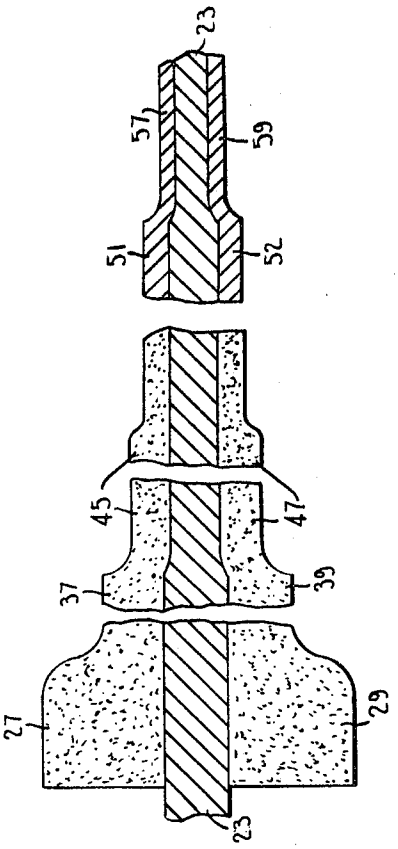


FIG. 3.

John F. Clarke,
Bruce J. Bliss,
Inventors.
Koenig, Senniger, Powers and Leavitt,
Attorneys.

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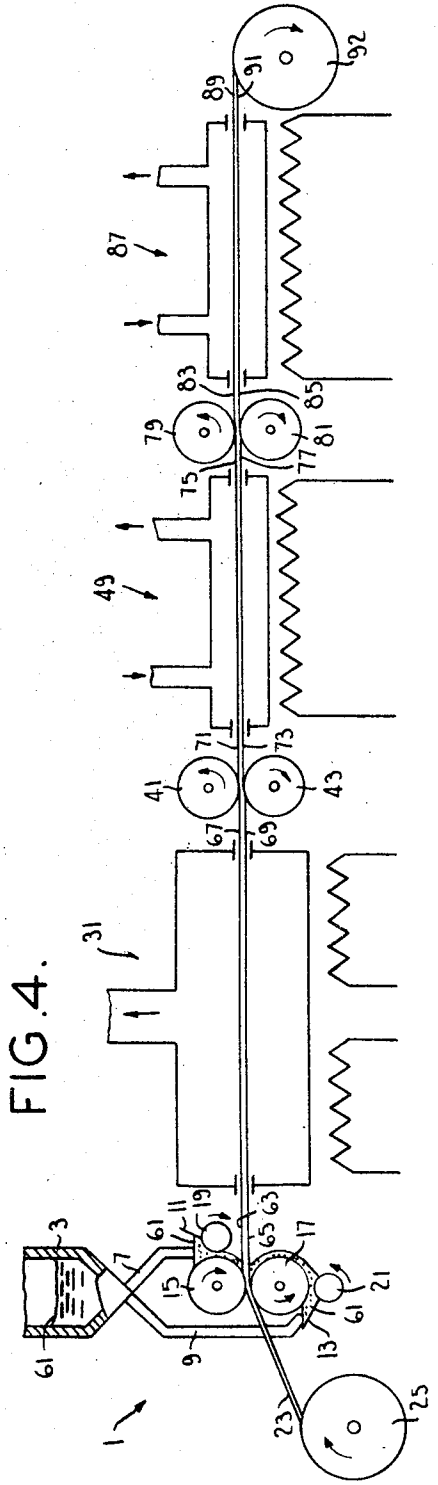


FIG. 4.

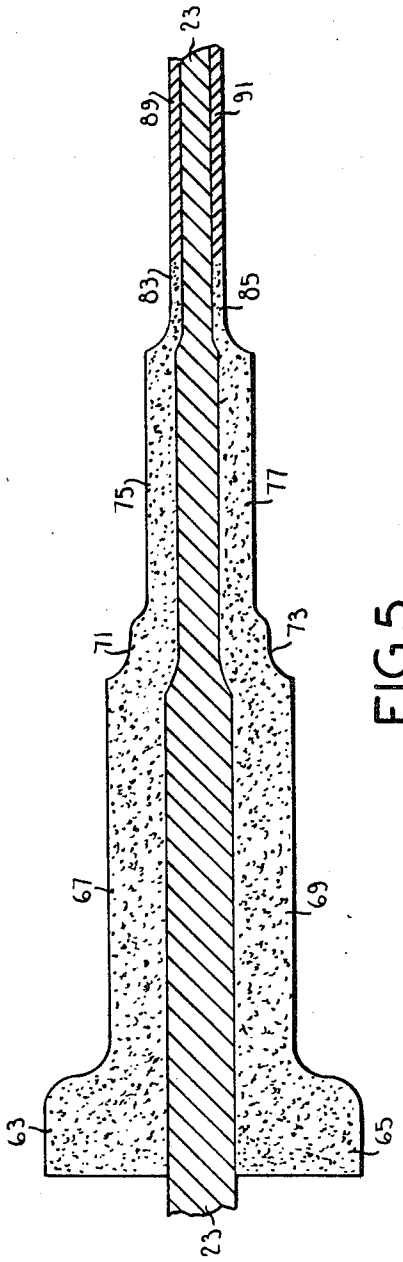


FIG. 5.

John F. Clarke,
Bruce J. Bliss
Inventors.
Koenig, Senniger, Powers and Leavitt,
Attorneys.

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MANUFACTURE OF CLAD METALS

John F. Clarke, Attleboro, and Bruce J. Bliss, North Attleboro, Mass., assignors to Texas Instruments Incorporated, Dallas, Tex., a corporation of Delaware

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U.S. Cl. 72—46 4 Claims

ABSTRACT OF THE DISCLOSURE

In one enbodiment of the disclosure a steel base strip is coated with a slurry containing particles of elemental metal, or particles each of which in and of itself is a metal alloy. Most of the particles in the slurry are substantially spherical and in the range of from 15 to 44 microns in size. The slurry contains a binder and is solidified on the strip by heating and drying and then rolled to effect solid-phase green-bonding between the particles and between some of them and the strip. The rolled strip is then sintered and again rolled to the desired finish and gauge. In another form of the disclosure a metal base strip is coated with a similar slurry, except that the metal powder suspended therein is composed of a mixture of particles of two different alloyable metals capable of forming a desired alloy which may be brittle. The strip is heated to dry the slurry which is then rolled a first time to effect solid-phase green-bonding as before. In this case a first sintering step, after the first rolling, occurs at a comparatively low temperature sufficient only to improve the green bonds, without being high enough to effect any sufficient diffusion for homogenization and alloying. The sintered clad metal is then rolled a second time to substantially its finished thickness and then sintered a second time at a comparatively high temperature sufficient for diffusion and homogenization so as to form the desired alloy. Thus alloys may be clad which may be brittle.

Among the several objects of the invention may be noted the provision of apparatus and methods for accurately cladding a base material with metal formed from various powders; the provision of methods and apparatus for simultaneously cladding metals on two surfaces of a metal base material when double cladding is demanded; the provision of methods and apparatus for cladding a base material with a metal or metal alloy which is normally too brittle to process conventionally, wherein the metal remains ductile during most of the manufacturing process; the provision apparatus and a method for cladding base materials with alloys either from mixtures of elemental metal powders or from prealloyed powders; and the provision of a method and apparatus for cladding base materials wherein large inventories of specific alloys usually required for cladding several alloys on base materials can be replaced with a smaller number of standardized alloying materials in powder or particle form. Other objects and features will be in part apparent and in part pointed out hereinafter.

The invention accordingly comprises the methods, apparatus and products hereinafter described, the scope of the invention being indicated in the following claims.

In the accompanying drawings, in which several of various possible enbodiments of the invention are illustrated,

FIG. 1 is a diagrammatic view, with certain parts broken away, illustrating the manufacture of clad metal in accordance with one embodiment of the invention;

FIG. 2 is an enlarged fragmentary view, with parts

broken away, illustrating a roller coater of the FIG. 1 apparatus;

FIG. 3 is a view illustrating diagrammatically modifications of certain materials as they pass through the process according to the first embodiment;

FIG. 4 is a diagrammatic view, with certain parts broken away, illustrating the manufacture of clad metal in accordance with a second embodiment of the invention; and

FIG. 5 is a view illustrating diagrammatically modifications of certain materials as they pass through the process according to the second embodiment.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

It is known to clad metal base materials with sheets or powders of the clad metal. Attempts at using powders have been directed at metering measured amounts of dry powder onto a substrate or base strip, then compacting and sintering this powder onto the substrate. However, it is difficult accurrately to meter dry powder onto the substrate in uniform thicknesses. Moreover, two surfaces of a base material strip cannot by such a process be simultaneously coated with dry powders. To obtain desirable economy of operation, both upper and lower surfaces of the base material should preferably be simultaneously coated during the process. By use of the process and apparatus of the invention, both the upper and lower surfaces of a base material may be accurately clad from a slurry containing powders of the clad metal.

In the following description, reference to metals used is intended to include alloys thereof, including, but without limitation, the metals nickel, copper, aluminum, iron, tin, boron, silicon chrominum et cetera. The terms clad metal or clad materials as used herein refer to a base material (such as steel for example) on which thin sheet metal has been adhered, the sheet metal thickness being a minor part of the over-all thickness of the clad maerial. The total thickness of the clad material may be 0.008" or less, although greater thicknesses are not precluded. For this total thickness, each layer of cladding on the base will have a finished thickness of, for example, about 0.0007" to about 0.001" although these gauges may be varied, depending upon the final thicknesses desired as determined by the intended use of the clad metal. The term slurry as used herein means a liquid medium of suitable viscosity containing a metal particle suspended in a binder. Binder means a long-chain high-molecular-weight organic compound or the like, characterized in that its constituents when comminuted are stringy, and when mixed with a liquid (such as water) smell and act according to the invention to hold or bind the metal particles in suspension and to produce adequate viscosity of the slurry. Thus the slurry will adhere evenly to metal surfaces contacted by it.

Examples, but without limitation, or suitable binders are polyethylene oxide, methyl cellulose, nonionic cellulose ether, polyvinyl pyrrolidone, et cetera. The intended use of the clad metal will determine the particular gauge to which it is manufactured. All drawings are illustrative and not to scale because of the small dimensions involved.

Briefly, the process for manufacturing clad metals according to one embodiment of the invention comprises coating a base trip (preferably metal) with a slurry containing metal powder suspended in a binder, solidifying the slurry by heating and drying it, compacting the slurry on the base strip to effect some green bonds between particles of the metal powder in the slurry and between some of these particles and the base strip, then sintering the combination base strip and coating, after which the

assembly may be further compacted to the desired final finish and gauge.

In another embodiment of the invention, the cladding metal is an alloy manufactured from elemental powders. This embodiment follows the steps set forth above except that the sintering step is at a temperature sufficient to cause growth of the green bonds between the metal particles within the coating and between the metal particles and the base strip but without being high enough to effect sufficient diffusion for homogenization and alloying between the particles in the coating or between the particles in the coating and the base material. Thus there is no significant alloying of the elemental powders during this sintering step. The clad metal is then sintered a second time, the last sintering step being under time and temperature conditions which effect alloying between substantially all of the particles in the coating.

The basic ingredients of the coating slurry are a binder (such as the ones mentioned above), a liquid and metal powder. The liquid may be water or alcohol, for example. When using methyl cellulose as a binder, a 400 centipoise (cps.) grade of methyl celluose is dissolved in a solvent such as water to obtain the desired solvent-binder viscosity. A viscosity of about 1000 to 1500 cps. 2.5% to 2.6% concentration of methyl cellulose) has been found satisfactory for applying a layer of the slurry to a strip by a dip-coating process. Polyethylene oxide in the grade designated number 205 has also been used satisfactorily. It can be used in concentrations of up to 5%, with a resulting viscosity of about 2500 cps., and thins quickly in water. The viscosity of the slurry may vary, depending upon the metal particle size, particle concentration and the manner of applying the coating to the base material. For roller coating the solvent-binder solution to the base material, a viscosity of about 2000 cps. plus or minus 10% has been found to produce good results. For 2000 cps. viscosity, a liquid-solid ratio of about 1 to 2.0–3.0 parts (by weight) has been found satisfactory. In some (but not all) cases a conventional wetting agent such as an aerosol may be used to advantage in the slurry.

The metal particles used in the slurry may be either elemental metal particles or particles which in and of themselves are alloys. We have found that for a given mass of powder most of the particles in the mass should be in the range of from 15 to 44 microns in size and should be of the more or less spherical type, rather than of flat or flake form. This is because the sizes and shapes of the metal particles or powders have also been found to affect the final result. For example, more or less spherical powders in the sizes stated (such as AMS 4778 braze alloy powder and Sherritt-Gordon nickel powder) were found to coat and bond more readily to the substrate than more or less flat or irregularly shaped powders such as INCO 100 nickel powder.

In general, it will be understood that bonding of the particles to the base strip is promoted by the following characteristics: hardness of the particles in relation to the strip, certain particle shapes such as spherical, and large particle size.

FIGS. 1 and 2 of the drawings illustrate apparatus for cladding base metal strips or substrates with metal originally in the powder form, the powder being composed either of elemental metal particles or particles of an alloy. A reverse roller coater for applying the slurry to a base material is shown generally at **1** and includes a reservoir **3** into which the slurry **5** is placed after it has been thoroughly mixed. The roller coater has passages **7** and **9** through which slurry **5** is transferred from reservoir **3** to an upper trough **11** and a lower trough **13**.

The roller coater includes two spaced coating rolls **15** and **17** which may be covered with semihard rubber. Adjacent the coating rolls **15** and **17** are two metering rolls **19** and **21**. Rolls **15** and **19** are rotated in a clockwise direction as viewed in FIGS. 1 and 2, whereas rolls **17** and **21** are rotated in a counterclockwise direction. The coating rolls and their respective metering rolls are spaced from each other and their separation may be varied to regulate the thickness of the coatings to be applied. Also, the speed at which the coating rolls turn may be varied. For example, the surface speed of the coating rolls may be varied from about 6 f.p.m. to about 20 f.p.m.

A flexible metal base strip **23** is unrolled from a reel **25** and passed between the coating rolls **15** and **17**. The rolls **15** and **17** deposit thin layers or coatings **27** and **29** of slurry on opposite sides of the base metal strip. The metal is any one desired in the final product, such as steel, for example. The thickness of the base metal strip **23** is not critical and may vary. Its thicknesses will be determined by the gauge desired for the final clad metal and by the percent reduction to be achieved during the rolling steps as described later. A suitable thickness range is from .005" to 0.015", although greater thicknesses are not precluded. The thickness of the wet slurry coatings or layers **27** and **29** may be, for example, 0.005" to 0.030" when wet. Preferably, each of the coatings is composed of the same metal particles and of the same thickness, although these may be different. The coatings are held on the base material at this time by the binder, which adheres to the surface of the base material.

Next the wet slurry coatings **27** and **29** are dried on the base metal strip **23**. This may be accomplished in an electrically heated chamber, generally designated **31** in FIG. 1. Chamber **31** is preferably relatively long (for example, about 12 feet) so that the drying may be accomplished under mild temperatures and over a time interval, as for example from several seconds to a few minutes, so as to avoid formation of bubbles or blisters. The temperature in the first stage **33** (the left part) of the chamber **31** is preferably at or slightly above the evaporation or boiling point of the liquid in the slurry. For example, when using water as a liquid, the temperature is stage **33** of chamber **31** may be slightly above 212° F. Thus as the coatings **27** and **29** are dried, the liquid is boiled off and may be removed through a flue designated **35**. The temperature is variable, depending on the solvent used. For example, using alcohol as the solvent, a lower temperature may be used since it is highly volatile and will be boiled off at a lower temperature.

The right-hand portion or stage of the heating chamber **31** is designated **36**. This stage is at a temperature which is sufficient to drive off some (but not all) of the binder in the slurry. When using polyethylene oxide or methyl cellulose as the binder, a temperature applied in stage **36** for several seconds to a few minutes or so at about 450° F. has been found satisfactory. The heating should be such that not all of the binder material will disappear. Thus all of the binder should not be driven off at this stage. The dried coatings should not be entirely freed of the binder since it is the binder that causes them to adhere to the base metal strip **23** at this time. The dried coatings are indicated at **37** and **39** in FIGS. 3 of the drawings. The coatings **37**, **39** are thinner than the wet coatings **27**, **29** due to removal of solvent and binder.

Strip **23** with dried coatings **37** and **39** thereon is passed through rolls of a rolling mill where it is compacted by squeeze rollers **41** and **43**. The thickness of strip **23** is reduced about 10% to 20% by rollers **41** and **43** and the density of the coating or layers **37** and **39** is increased from approximately 50% to about 90% of their theoretical density during this rolling step. As a result of this compaction, particles of the metal in the dried coatings **37** and **39** in the solid phase are green-bonded to each other and also to the carrier or base strip **23**. By using a substantial proportion in the slurry of more or less spherical metal powders of the above-given 15 to 44 micron size, particles of metal in the coatings are pressed or ground into the surfaces of the base strip during this compaction. Neither smaller-size

nor flatwise particles are as easily ground into the base material and thus do not produce the most effective bond between the base and the coatings. However, the inclusion of some smaller sizes of particles is acceptable, provided there are a substantial number in the size range stated.

After compaction, the base strip **23** and the coatings are sufficiently green-bonded together to permit them to be handled in a coil if desired. The compacted coatings are designated **45** and **47**, respectively, in FIG. 3. The coatings **45** and **47** at this stage are porous enough to provide paths for escape of the remaining binder during the subsequent sintering step.

Next the compacted base strip and coatings are passed through a sintering furnace **49**. While in FIG. 1 they are shown passing through the furnace in a continuous process, it will be understood that the coated strip can be coiled and then placed in the sintering furnace if so desired. The time and temperature cycle of the material in the furnace is controlled to effect vaporization of any binder that remains in the coatings **45** and **47**, to substantially completely densify the coatings **45** and **47** by diffusion of the metal in the coatings and by bond growth, and to improve the bond between the particles of the coating and the base strip **23**. Protective or reducing atmospheres may be provided in furnaces **31** and **49** if desired, to prevent or reduce oxidation. For example, argon, hydrogen, cracked ammonia or other known gaseous atmospheres may be used.

As an example, a stainless steel base strip **23**, clad with an AMS 4778 braze alloy, may be sintered at a temperature of about 1830° F. to about 1860° F. for about three minutes in a hydrogen-reducing atmosphere. It will be understood that the time, temperature and atmosphere will vary, depending upon the materials constituting the clad metal. After sintering, the coatings **45** and **47** are strongly bonded to the base **23**. The sintered coatings are designated **51** and **52** in FIG. 3.

Following the sintering step, the coated product may, if desired, be further processed or finished by conventional metallurgical techniques. As illustrated in FIG. 1, this includes passing the clad metal through a rolling mill having squeeze rolls **53** and **55** for compacting the clad metal to final thickness and for smoothing its surfaces. Preferably the rolls **53** and **55** are at least 5″ in diameter when the base strip is clad with brittle metals (such as nickel-based brazing alloys) and the compacting effected by the rolls **53** and **55** is preferably not more than 20% of the thickness of the clad strip. The final compacted layers on carrier **23** are designated **57** and **59** in FIG. 3. These layers are firmly bonded to the carrier **23** and resist separation from the base strip. The layers **57** and **59** are very dense and substantially pore-free. The ratio of thicknesses between the base strip and the final clad layers is variable, depending upon initial thicknesses of both, but a base strip gauge of about .006″ and layer thicknesses of about .001″ (for a total thickness of .008″) may be readily achieved. The clad metal may be wound on a reel, as shown at **60**.

The following is a particular example of how the above-described first form of the invention has been performed:

A quantity of 400 cps. methyl cellulose was dissolved in water to obtain a solvent-binder viscosity of about 1000 to 1500 cps. (2.5% to 2.6% concentration of methyl cellulose). To this was added a sufficient amount of prealloyed AMS 4778 alloy powder of an average particle size of 24 microns to obtain a slurry mixture containing 60% to 80% metal powder. The AMS 4778 braze alloy powder used was about 4½% silicon, 3½% boron and 92% nickel. Each particle of the powder was composed of this alloy. A steel base strip having a thickness of about 0.010″ was then coated by the slurry. The resulting coatings or layers adhering to both surfaces of the strip were heated for drying and driving off some of the binder on the strip. The strip was then roll-compacted in a rolling mill, which forced the particles together for green bonding between them and forced some into the steel strip while green-bonding them thereto. The strip was then sintered and rolled to a final thickness of about 0.006″. Sintering improved the green bonds. The thickness of the braze alloy clad on the steel was about 0.0007″ to about 0.001″.

Another starting material that has been used is No. 205 polyethylene oxide, mixed with water to obtain a 3.6% solution. This solution was then mixed with prealloyed AMS 4778 braze alloy powder in the ratio of 1 to 2.4 parts by weight and the process carried out as above described to produce a uniform pore-free coating. In general the solid content of the slurry is preferably about 60% to 80% of the weight of slurry in order to obtain coating thicknesses of about 0.001″.

The process and apparatus set forth in the preceding description are especially useful in the manufacture of clad strips, the most useful powders of metal being prealloyed braze powders. However, this does not preclude the use of an elemental powder. As previously noted, rolling of the coated strip to final gauge after sintering is preferably accomplished at compactions of not more than 20%. This is desirable, since the braze alloys are normally brittle and compactions or more than 20% may result in cracking of the clad metal.

The process and apparatus of FIGS. 4 and 5 permit greater compaction without cracking of the clad metal. Briefly, this is accomplished by providing mixtures of different elemental metal powders of the desired alloy. These are placed in the slurry (as opposed to adding the powders of prealloyed metals or one elemental metal) and by delaying final alloying of these elemental metals until after the clad metal and its carrier strip have been rolled substantially to the desired finished thickness.

In carrying out the invention in the embodiment set forth in FIGS. 4 and 5, a slurry **61** is first mixed, containing powders of the several elemental metals which are to constitute the final alloyed braze clad metal on the base strip **23**. These elemental metal powders may be mixed with binders and solvents of the type previously set forth and, with the exception of the combination of metal particles used, the slurry **61** may be the same as that previously described. Typical mixtures of elemental powders which may be used in slurry **61** comprise 3.5% boron powder, 4.5% silicon powder and 92% nickel powder (equivalent to AMS 4778 braze alloy), or, for example, a mixture comprising 19% chromium metal powders, 10% silicon powders and 71% nickel powders (equivalent to GE–81 braze alloy). In mixing the slurry, spherical powders having an average particle size of less than —325 mesh have been found to be satisfactory. A suitable range for most particles in a given batch is 15 to 44 microns. A final slurry viscosity may be (for example) 2000 cps. after stirring for thirty minutes.

After the slurry is thoroughly mixed, it is applied to a roller coater apparatus again generally designated **1**, which may be of the type and operate in the manner previously explained. A base metal strip **23** is unrolled from a reel **25** and passed through the roller coater between the coating rolls **15** and **17** where coatings **63** and **65** (FIG. 5) are applied to the base metal strip. These coatings are adhered to the strip by the binder in the slurry and they are preferably substantially uniform in thickness.

The carrier strips **23** with coatings **63** and **65** thereon is then run through a heating chamber **31** which is like the chamber **31** in FIG. 1 previously described. Thus the slurry coatings are dried by heating, the solvent in the slurry is vaporized and driven off, and a portion (but not all) of the binder may be removed as previously described. The resulting dried coatings are designated **67** and **69** in diagrammatic FIG. 5. Next the base metal strip and the dried coatings are run through a rolling mill where the

squeeze rollers **41** and **43** compact the dried coatings and also compact the base metal strip **23**. The base strip may be compacted by about 10% during this step. This compaction of the coating and base strip results in portions of the powders of the coating being ground into the base strip along its coated surfaces, thereby effecting a solid-phase green bond between the lower particles of the coating and the metal of the base strip. At the same time, compaction of the coatings **67** and **69** results in green-bonding between particles of metal within the dried coatings, thereby forming a matrix of the particles which is sufficient to hold them together as a cohesive mass. The result of this rolling is the same as that previously described in connection with FIGS. 1–3. The compacted coatings are designated **71** and **73** in FIG. 5.

Next the base strip and coatings are sintered in a furnace **49**. The temperature selected for the sintering is above the temperature required to effect grain growth and diffusion of like metal particles within the coatings **71** and **73** (e.g., diffusion and grain growth between nickel particles) but at the same time the temperature is sufficiently low to prevent any significant amount of homogenization or alloying of the different types of metal particles within the coatings. Thus substantially all of the metals in the coatings following this sintering step are in the elemental form (not alloyed). The sintered coatings are illustrated at **75** and **77** in FIG. 5. Since the coatings are substantially free of metal alloys, they remain ductile and are easily worked following this first low-temperature sintering step. If the sintering temperature were high enough to effect substantial alloying of the particles within the coatings during this sintering step, then the resulting coatings would be too hard and brittle sintering furnace **49** may be uneven.

Next the base strip **23** and the initially sintered coatings **75** and **77** are passed between squeeze rolls **79** and **81** of a rolling mill where they may be compacted a substantial amount. For example, compaction between rolls **79** and **81** may be on the order of 40% or more without severe cracking of the coatings. The clad metal is rolled to substantially its final thickness by the rolls **79** and **81** and the metal particles in the coatings **75** and **77** are compacted by these rolls to increase the density of the metal in the coatings. The squeezed coatings are designated **83** and **85** in FIG. 5. The amount of compaction of the coatings by rolls **79** and **81** may vary from simply a kiss pass for effecting approximately 5% to 10% reduction in thickness to a substantial reduction in thickness (e.g., 40% or more). Since the coating at this time is composed essentially or elemental metals (i.e., there is substantially no metal alloy), this substantial compaction can be achieved without severe cracking of the coating. At least a kiss pass is desired at this time since the coating leaving sintering furnace **19** may be uneven.

Next the base strip **23** with the coatings **83** and **85** thereon is run through a sintering furnace **87** which is at a temperature substantially higher than the temperature in furnace **49**. The time-temperature cycle in furnace **87** is such that there is diffusion between the elemental metals in coatings **83** and **85** to homogenize all of the constitutent metals in the coatings into the alloy of which they are the constituents. At the same time, diffusion occurs between the metal of the base strip **23** and the coating layers to provide an intermediate zone between the center of the base strip and the outer portion of the coating layers which is an alloy of the clad metal alloy and the base strip metal. The resulting clad metal is very dense and is strongly adhered to the base strip. The clad alloy is designated **89** and **91** in FIG. 5. The final alloying by diffusion may cause embrittlement of the coatings but this is not detrimental since manufacture of the clad metal is complete. The clad metal may then be wound on a reel, as shown at **92**.

The following is a particular example of how the process of the FIGS. 4 and 5 embodiment of the invention has been performed:

AISI No. 321 stainless steel strip having a thickness of about 0.005" was coated by means of a roller coater with a slurry comprising a binder, a liquid and a mixture of metal powders comprising approximately 19% chromium, 10% silicon and the balance nickel powder. The actual slurry was made by adding 236.5 gm. of INCO 255 nickel powder (an easily sintered powder of pure nickel), 56 gm. of −325 mesh chromium powder, and 33 gm. of −325 mesh silicon powder in a solution containing polyethylene oxide and water. The metal powders were substantially spherical powders which promote bonding with the strip **23** during the initial rolling step. The metal powders were mixed with a solution of polyethylene oxide and water to provide a final slurry viscosity of about 2000 cps. after stirring for thirty minutes. After the slurry was coated on the stainless steel strip, it was dried in a furnace where a substantial part of the solvent (water) was driven off and some of the binder was vaporized.

Then the base strip and the dried coatings were passed through a rolling mill where the coatsings were compacted. This occurred at a pressure sufficient to effect aproximately 10% reduction in the thickness of the base strip. As a result of this hard compaction, solid-phase green bonding occurred between particles of nickel silicon and cromium in the coatings. Also, there was a solid-phase green bond between particles of metal in the dried coatings and the metal of base strip **23** for holding the coatings on the base strip. The size and shape of the metal particles, and the compaction of the base strip by about 10%, resulted in the coatings being firmly green-bonded to the base strip.

Next the compacted coating and base strip were passed through a sintering furnace where sintering occurred at approximately 1400° F. This temperature was less than the temperature at which unlike metal particles in the coating would homogenize to form a nickel-chromium-silicon alloy. As a result, this sintering step produced only sufficient grain growth and diffusion between particles to green-bond them. Since no significant amount of alloying took place at this time, the sintered strip remained ductile and could be easily worked.

Next the composite strip was further squeezed by passing the strip through a rolling mill. It was found that this composite could be rolled with at least 40% reduction without severe cracking of the coating due to the absence of any substantial amount of alloying of the metal in the coating. The strip was compacted to its final gauge and was then passed through a second sintering furnace at about 1900° F. and for a time (several minutes) sufficient to completely diffuse and homogenize the metals in the coatings to form a homogenous alloy of nickel, chronium and silicon. The resulting alloy was brittle.

Which of the two embodiments of this invention will be used for cladding base strips will be determined in part by the characteristics of the metal which is to be clad on the base strip. For example, if a ductile metal or metal alloy is being clad, then the process and apparatus described in connection with FIGS. 1–3 may be used, since no unusual difficulty should be experienced in compacting the clad metal to the desired final gauge and only one sintering step is required. No sintering step for alloying is required. Also, if the thickness of the clad metal is such that it can be successfully compacted to substantially final gauge prior to sintering, even though it is brittle, then the FIGS. 1–3 process and apparatus can be used. However, where the resulting clad metal is very brittle and where substantial reduction in thickness of the clad metal layers and the base material is desired, then the process and apparatus described in connection with FIGS. 4 and 5 will be used since undesirable cracking will not occur. Where a large number

of alloys are to be used and there is one elemental metal as the basic ingredient of the alloy (such as various nickel-based braze alloys) then the process described in connection with FIGS. 4 and 5 will be most desirable since only a few standard alloying powders need to be stocked and combined in the desired final ratio, rather than a large number of similar prealloyed metal powders.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantages results attained.

As various changes could be made in the above methods, apparatus and products without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. The method of manufacturing clad metal strip comprising:

coating on at least one side of a metal base strip a layer of a slurry containing a binding compound, a solvent and powdered metal most of the particles of which are substantially spherical, substantially in the range of 15–44 microns in size and substantially all of which are harder than the metal of the strip,

heating said layer on the strip at a relatively low temperature to dry it and drive off some but not all of said binding compound,

rolling the layer against the strip under pressure sufficient to reduce the thickness of the layer and the strip while grinding some of the particles into the strip as it is being reduced and to solid-phase green-bond the particles to each other and some of them to the strip during its reduction, and

heating the layer and the base after reduction at a relatively high temperature to drive off the remaining binding compound from the layer and to improve said green bonds between said particles in the layer and between those of the particles and said reduced base as have been ground into it.

2. The method of manufacturing clad metal strip comprising simultaneously cladding each side of a metal base layer according to claim 1.

3. The method of manufacturing clad metal strip comprising:

coating on at least one side of a metal base strip a layer of a slurry containing a binding compound, a solvent and powdered metal particles of at least two different alloyable metals most of the particles of both of which are substantially spherical, substantially in the range of 15–44 microns in size and substantially all of which are harder than the material of the strip,

heating said layer on the base at a relatively low temperature sufficient to drive off said solvent and some of but not all of said binding compound,

rolling the layer against the base under pressure sufficient to reduce the thickness of the layer while grinding some of the particles into the strip as it is being reduced and to solid-phase green-bond particles to one another and some of them to the strip during its reduction,

sintering the layer and the base at a moderate temperature to improve by diffusion the green bonds but without alloying between said alloyable particles in the layer or between the base and said particles,

again rolling the green bonded layer and base, and

subsequently again sintering the layer and base at a higher temperature to effect homogenization between particles of the different alloyable metals to form an alloy thereof.

4. The method of manufacturing clad metal strip comprising simultaneously cladding each side of a metal base layer according to claim 3.

References Cited

UNITED STATES PATENTS

3,121,631	2/1964	Comstock	29—420.5
3,316,625	5/1967	Flint et al.	29—420.5
2,372,607	3/1945	Schwarzkopf	75—208
2,681,375	6/1954	Vogt	75—222 XR
3,199,176	8/1965	Freudiger et al.	29—420.5 XR
3,330,654	7/1967	Sweet	75—208

CHARLES W. LANHAM, *Primary Examiner.*

E. M. COMBS, *Assistant Examiner.*

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