

[54] **PROCESS AND APPARATUS FOR
FABRICATING A HOT WORKED
METAL LAYER FROM ATOMIZED
METAL PARTICLES**

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29/DIG. 39, 164/46, 164/68, 164/76**

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164/50, 52, 68, 87, 276, 281, 76, 46**

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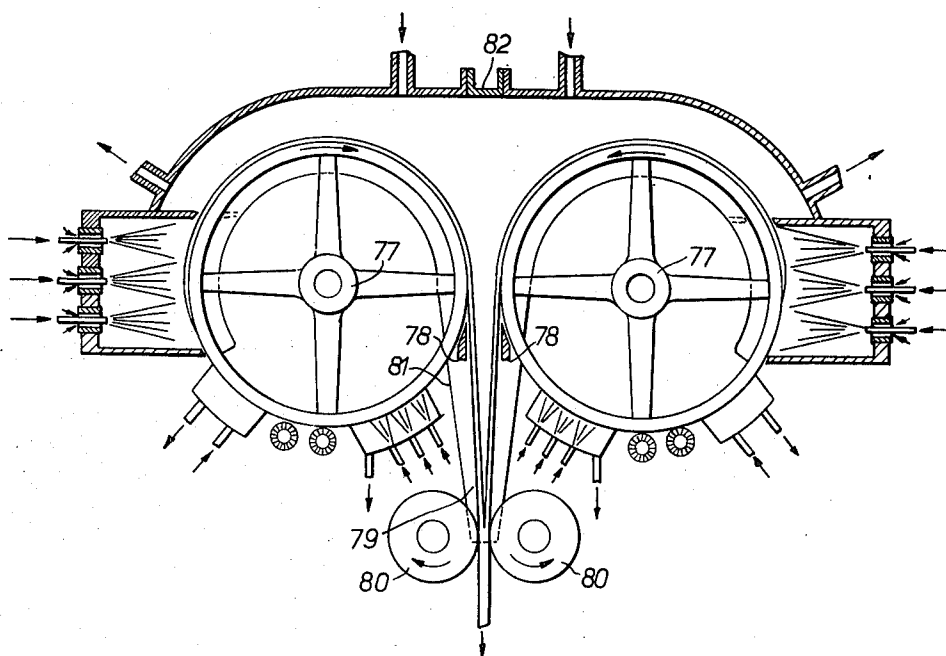
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ABSTRACT

A process for the fabrication of metal in shapes of long length and relatively thin cross section by deposition of molten metal on to a substrate and subsequent removal of the shaped metal article therefrom, in which a stream of gas-atomized particles of molten metal is directed on to a substrate, and caused to coalesce and form a coherent layer which is subjected while still hot to hot working, hot working being carried out either (a) before or after removal from a non-deformable substrate or (b) after removal from a deformable substrate.

31 Claims, 15 Drawing Figures



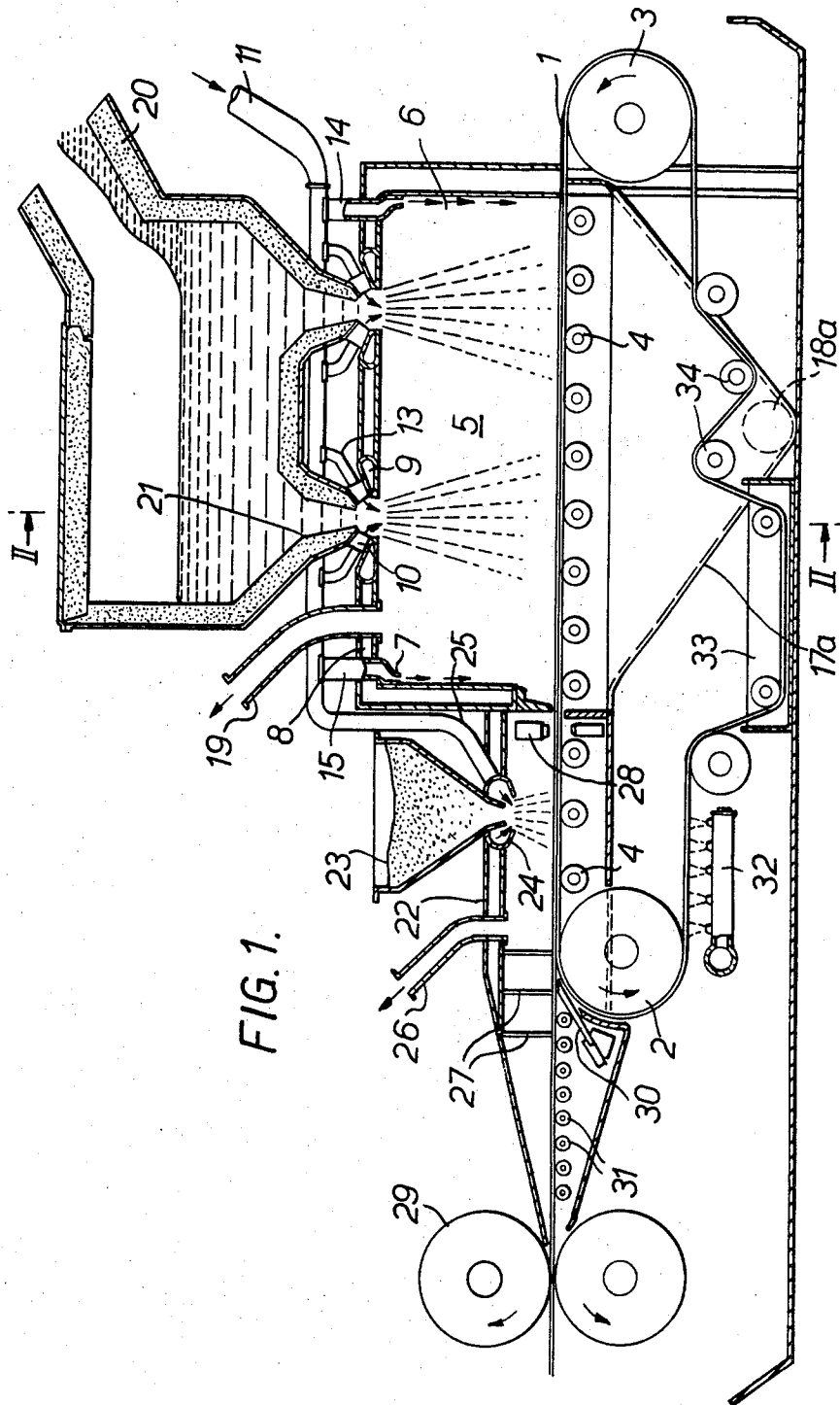
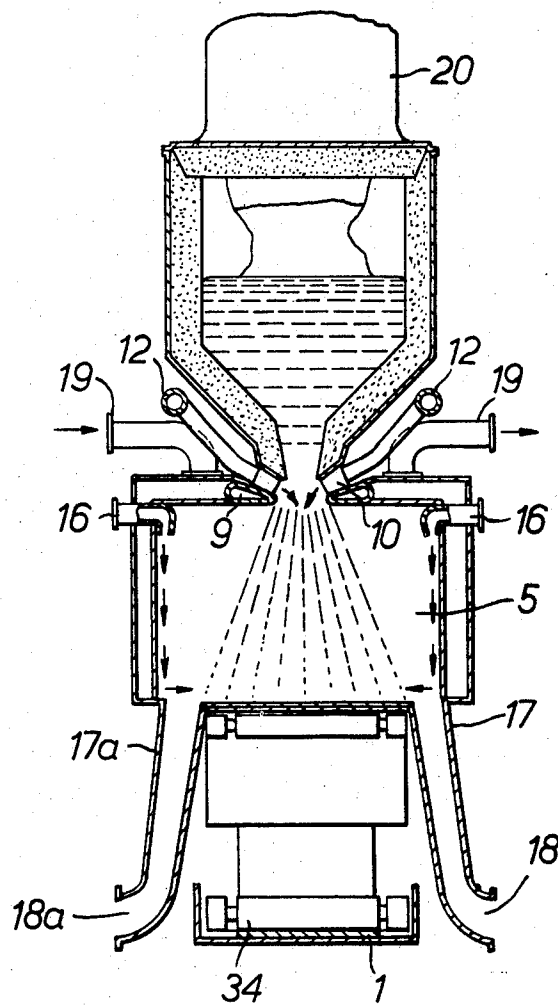


FIG. 1.

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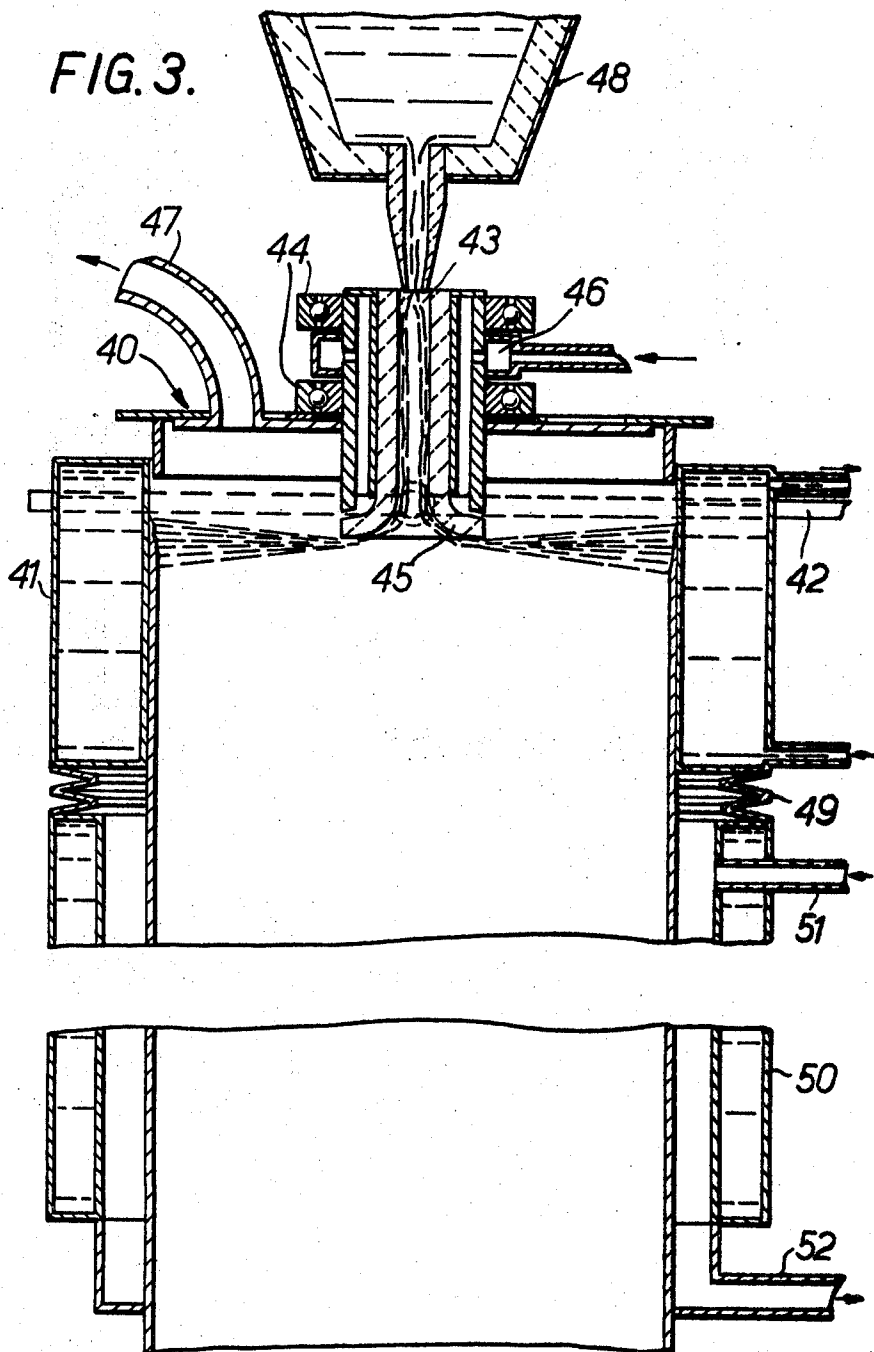
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FIG. 2.



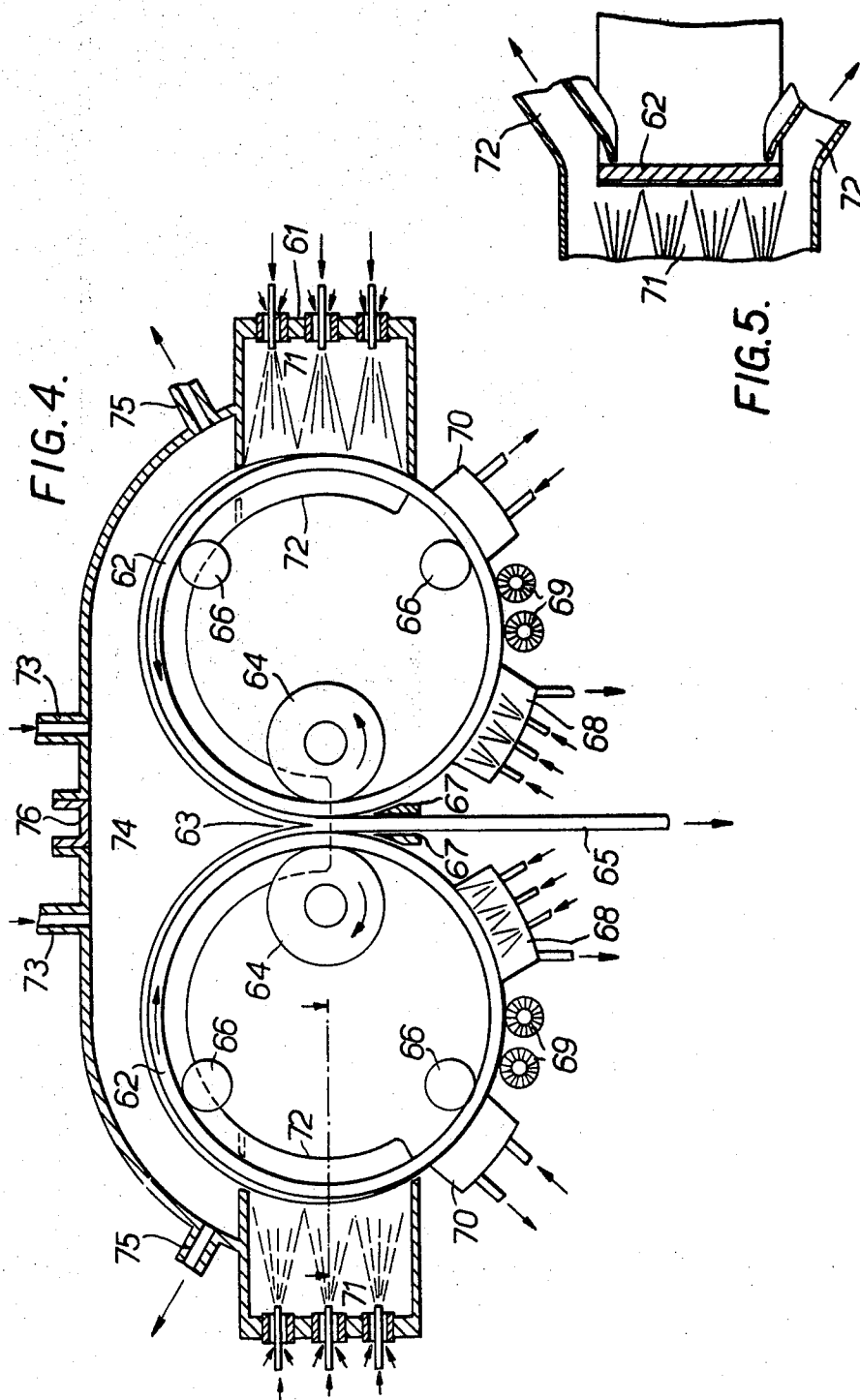
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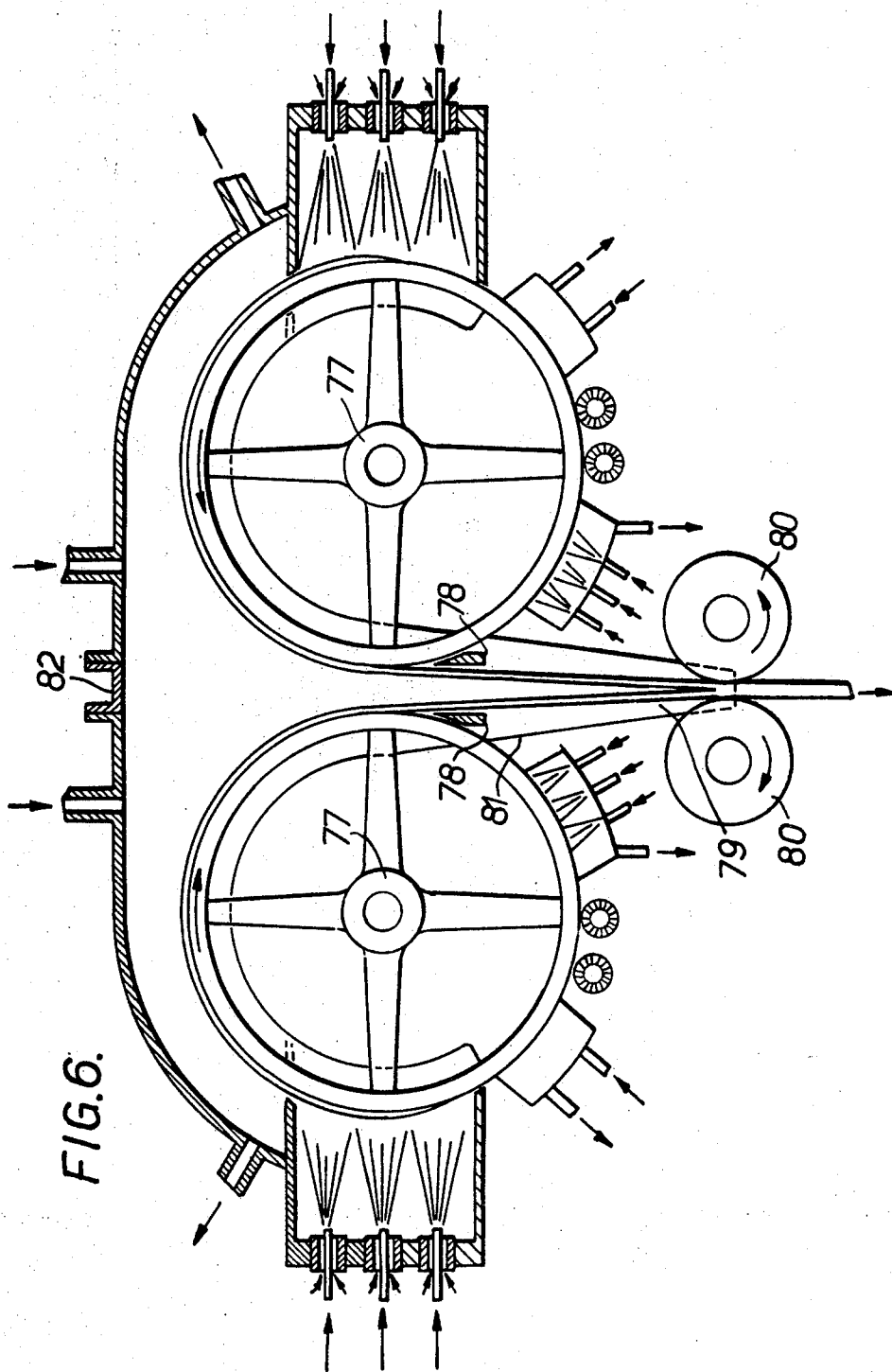
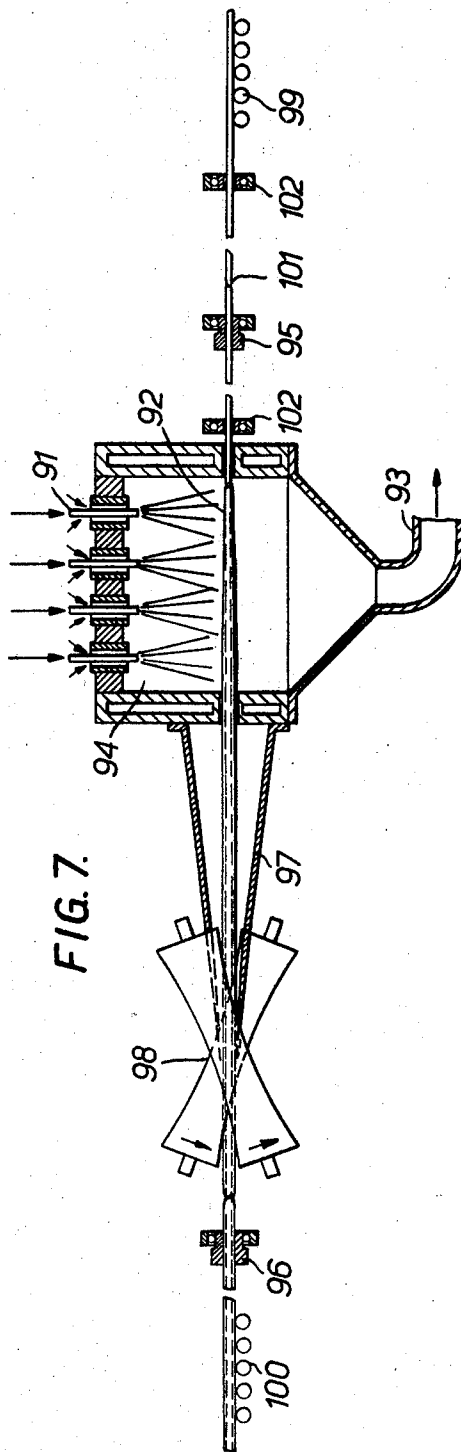


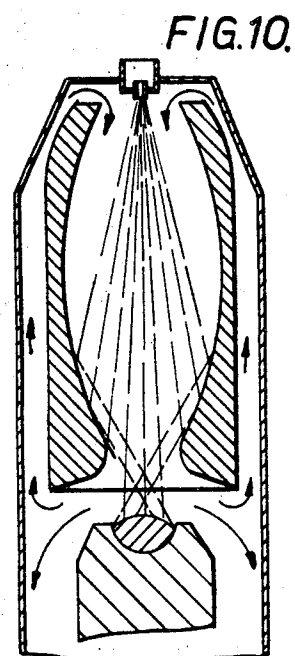
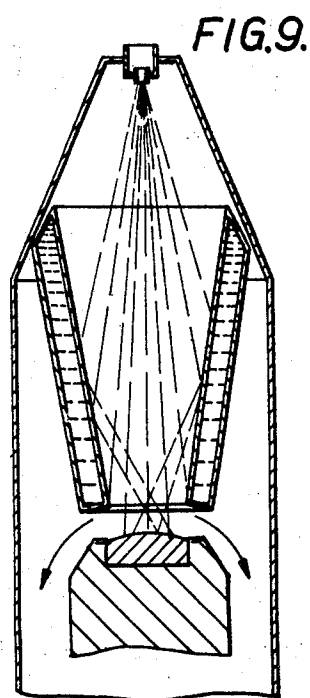
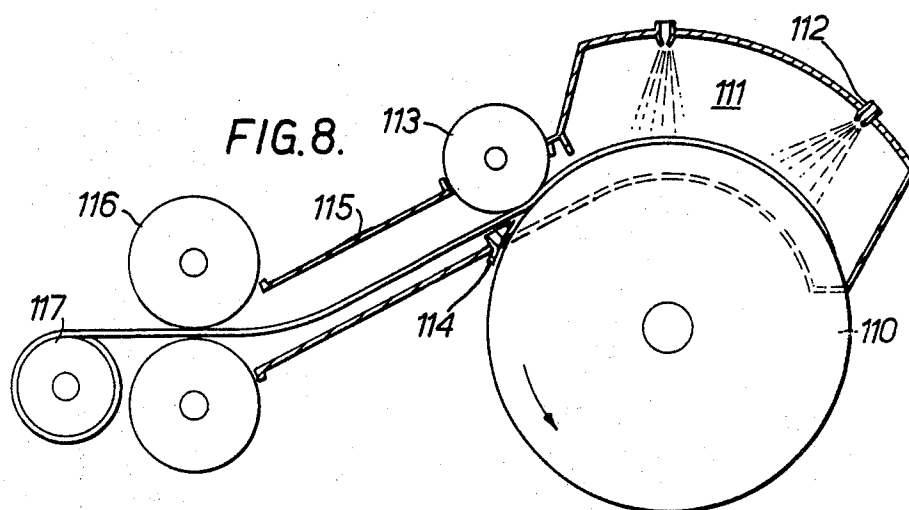
FIG. 6.

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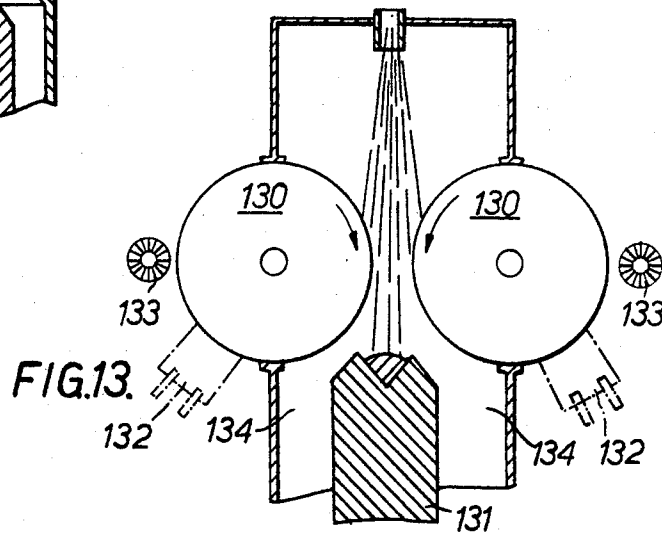
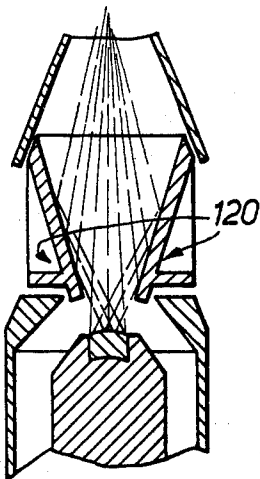
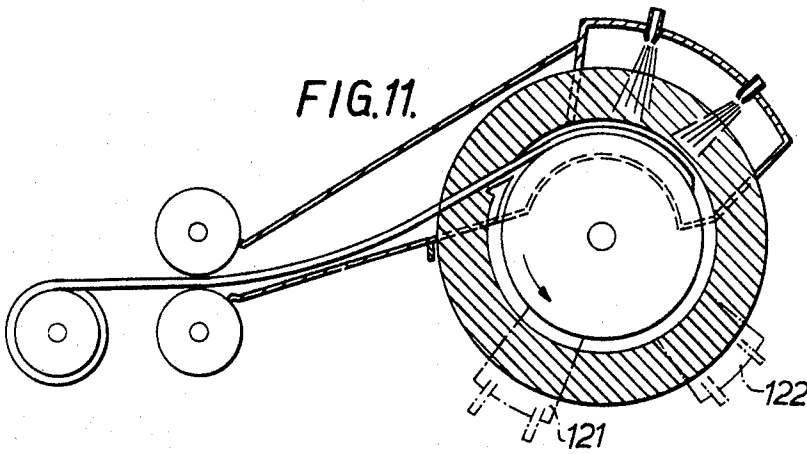
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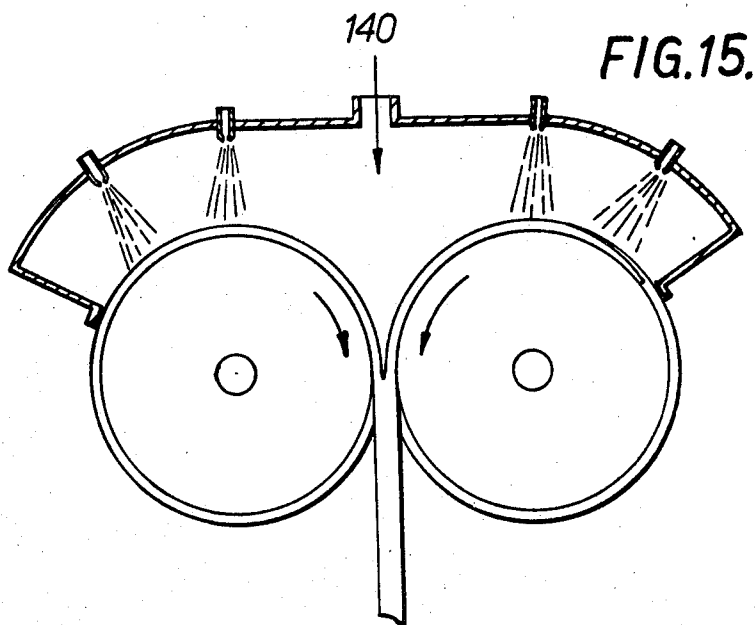
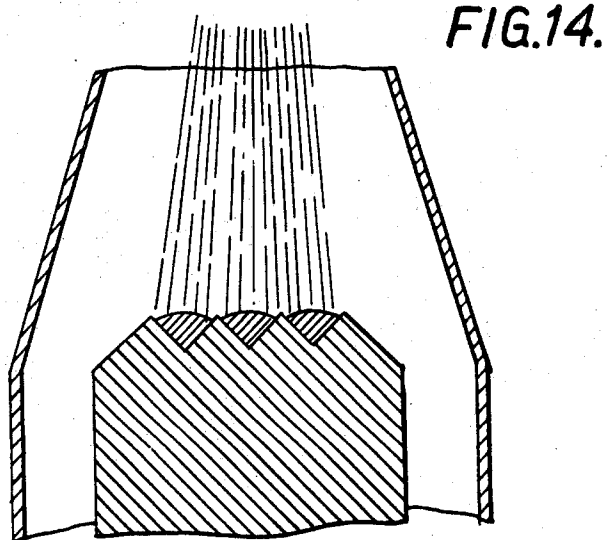
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PROCESS AND APPARATUS FOR FABRICATING A HOT WORKED METAL LAYER FROM ATOMIZED METAL PARTICLES

This invention relates to the fabrication of metal articles.

It has been realized for many years that there are advantages in producing metals in thin strip form by aggregating solid particles of the metal, rather than by reducing the material to the required section from massive ingots, and a very considerable amount of research in the field of powder metallurgy has produced an extensive literature. Although the direct rolling of powder to strip is a simple technique in principle, it involves many difficulties in practice, and in spite of extensive efforts which have been made to solve the problems involved metal strip is not produced by this method on any substantial scale. Among the difficulties mentioned are the limitations on the speed at which the powder can be fed into the rolling mill because of efflux of air and other considerations. Again, the green strip is relatively fragile and presents handling problems. An alternative approach to powder rolling involves the use of a binder thereby introducing additional complications due to the need firstly of incorporating and secondly removing the binder during subsequent processing.

It has now been found that metal products of excellent quality may be fabricated in shapes having extended or continuous length of relatively thin cross section, e.g. strip or tube by deposition of molten metal on a substrate to form a coherent layer which is subsequently removed from the substrate. An integral feature of the approach provided by the present invention is that the appropriate porosity and mechanical properties of the finished metal article are achieved by hot working the deposited metal after it has coalesced into a coherent layer while it is still hot. Surprisingly it has been found that the "green" layer formed on the substrate by coalescence of metal particles has sufficient strength and ductility to permit of its removal from the substrate as a self-supporting article even while still at the temperature required for hot working. This is particularly advantageous because one important method of fabricating metal according to the invention makes use of substrates which are of a thickness comparable to that of the metal layer, e.g. a continuous band substrate, in which case hot working of the metal while still in contact with the substrate is a practical impossibility because of the consequent distortion and eventual destruction of the substrate which would ensue.

According to the invention, metal is fabricated in shapes of long length and relatively thin cross section by deposition of molten metal on to a substrate and subsequent removal of the shaped metal article therefrom, in which a stream of gas-atomized particles of molten metal is directed on to a substrate, and caused to coalesce and form a coherent layer which is subjected while still hot to hot working, hot working being carried out either (a) before or after removal from a non-deformable substrate or (b) after removal from a deformable substrate.

The invention also includes an apparatus for the fabrication of metal in shapes of long length and relatively thin cross section which comprises a chamber provided with means for producing a stream of gas-atomized particles of molten metal and for directing the particles on to a non-deformable or deformable substrate located within the chamber in such a manner that coalescence of the particles occurs to form a coherent layer, means for hot working the deposited layer either before or after removal from the substrate as appropriate and while still hot, and means for withdrawing the deposited layer from the chamber.

Preferably the substrate is moved relatively to the particle feed so that a continuous layer of metalliferous material is deposited on the substrate.

Using the process of the invention metal articles may be produced directly from molten metal avoiding the casting and size reduction operations which are traditionally employed in the metal industry. Molten metal produced from an ore by smelting or other operation may be converted directly to strip, tube and other shapes by means of the technique hereinafter described.

Articles may be fabricated in a wide variety of cross sectional shapes by the process of this invention, but the process is especially applicable to the production of strips, tubes, rods and bars of common form. Metals which may be employed for the purpose of this invention may be in elementary form, or in the form of alloys or metallic compounds. High melting point materials including ferrous metals and alloys, e.g. carbon steels and alloy steels and a wide variety of non-ferrous metals and alloys including nickel, copper and aluminum may be employed in the process of the invention. Laminated materials such as aluminium/copper, copper/aluminium/copper, copper/iron/copper, iron/copper, iron/brass, iron/aluminium, aluminium/brass, stainless steel/iron, aluminium/iron and nickel/iron may be produced by applying atomized particles of the appropriate materials in succession and these have been found to have outstanding stability as distinct from laminates produced by prior methods which are prone to de-laminate during fabrication. Reinforcing or other materials may be inserted between successive layers and then subsequently compacted.

When it is desired to produce composite materials using additional components which are not readily incorporated in the main liquid feed the components may be directed on to the substrate separately either simultaneously or one after the other so that the additional component becomes incorporated into the deposited layer to form a composite material. Thus composite materials of this nature include, for example, those prepared from lead, which is immiscible with many other metals in the molten state and ceramics such as metal oxides in fine powder form. These compounds may be sprayed separately or together with the atomized liquid metal to form the coherent layer. In the case of metals such as lead, the spray may be in liquid or powder form. Materials incorporated in this way are thus finely dispersed throughout the layer formed on the substrate. If a material incorporated either in the liquid or by separate addition is required to be partly or completely aligned in one direction, then this result may be achieved by directing the stream containing the additional component at an oblique angle to the substrate. In the case of fibers incorporated in metals, alignment can be obtained by spraying the substrate surface at an oblique angle in the direction of travel of the substrate.

Composite materials having local variations of metallic composition are also readily obtainable including those which have successive adjacent areas of different composition, for example, alternating zones of two different metals.

In this way "twin" metals may be prepared consisting of, for example, copper at one end and steel at the other end with a tapered junction in between. Such a junction, formed by overlapping the sprays and subsequent rolling, is found to very strong because of the length of the interface. Similarly any number of combinations of different metals and alloys can be used.

The molten material may be atomized by means of any suitable gaseous agent, or partly by mechanical and partly by gas as, for instance, in the rotating blast bowl type of atomizer. Nitrogen, hydrogen or other inert or reducing gases are preferred in order to minimize the amount of oxidation where metallic elements are employed. While nitrogen or nitrogen-hydrogen mixtures are preferred many cheap and plentiful gases and mixtures thereof may be used provided they are clean and do not contain free oxygen. Thus a cleaned flue gas or blast furnace gas can be used for steel provided the CO:CO₂ ratio can be adjusted to give the required degree of carburization or decarburization in the product. Air may be employed where a measure of oxidation of the material is tolerable or alternatively where a product of the desired properties may be obtained by subsequent treatment under reducing conditions, e.g. in an atmosphere of hydrogen. The admission of controlled amounts of air or oxygen is advantageous where it is intended to incorporate metallic oxides in a fine state of division. For instance, aluminium alloy strip containing small quantities of dispersed Al₂O₃ may thus be produced. Such strip will then show dispersion hardening and inhibition of

grain growth. The advantages of gas atomization are that the latent heat of fusion of the particles can be extracted by the gas while the particles are in flight and that it tends to produce spherical rather than irregular particles. Such spherical particles become plastically deformed upon impact with the substrate on which they are directed and coalesce more conveniently into a continuous layer.

The atomized material may be supplied by means of a nozzle in the wall of the chamber and in practice it will be usual to employ a number of nozzles placed longitudinally and transversely with respect to the substrate. Alternatively, a stream of atomized particles may be generated by high pressure gas atomizing a thin film of liquid metal as it passes over a weir or through a slot extending across the width of the substrate.

Preferably the overall pressure in the chamber is maintained slightly above atmospheric pressure to prevent ingress of unwanted air into the chamber.

Where strip materials are to be produced, the substrate can be e.g. a continuous band, provided that the deposited layer is removed from the band before hot working, or a rotating drum. When tubular sections are to be formed the substrate can be a rotating mandrel.

The substrate on which the particles are deposited should have a surface such that the particles do not adhere to it, or do not adhere strongly to it since it will be necessary to remove the fabricated article from the substrate. Deformable substrates, that is to say those made from materials that would be plastically distorted or fractured under the conditions used in hot working the deposited layer, may be made from for example ceramics, vitreous materials or asbestos, and include substrates made from continuous metal bands. Non-deformable substrates are usually made from metal, and in this connection steel or copper substrates are particularly convenient. Both types of substrate may be used with a releasing agent if necessary. The surface condition of the substrate is an important factor and should not be too smooth for in these circumstances the deposition of the initial coherent layer on the substrate is made more difficult. By employing a suitably rough surface and judiciously selecting the velocity of the gas/particle stream, a primary layer of appropriate properties is built up following which the velocity of impingement may be increased.

When the method is applied in a continuous process, certain difficulties may be encountered arising from the necessity of continuous withdrawal of the deposited metal layer from the region wherein it is first formed. Thus in the continuous withdrawal of tubes in a downward direction or in the continuous withdrawal of flat products or simple open shapes in horizontal direction, it may be found that unsatisfactory products are obtained because parts of the deposit first formed adhere temporarily to the substrate and the action of withdrawal of the product results in the formation of a fracture in these regions.

In accordance with a further aspect of this invention, the process is conducted continuously and the substrate on which the metal layer is formed is subjected to a superimposed reciprocatory motion in a line parallel to the direction of movement of the substrate. The reciprocating cycle may be varied over a wide range but the substrate is preferably moved in the direction of movement of the substrate at a relatively slow forward speed for a short distance and then removed in the reverse direction at a relatively faster speed until the cycle is complete. A typical combination for a withdrawal speed of the deposited layer of 10 ft./per min. vertically downwards would be a substrate speed of 10.5 ft./min. downwards for 1 inch followed by an upward substrate speed of 30 ft./min. to complete the cycle. A releasing agent such as graphite suspended in an oil base, is sometimes found to be necessary and may be fed continuously as a thin film on to the substrate surface.

Flat products, and tubes made by depositing on the inside of a surrounding substrate, may be readily separated from the substrate by withdrawal but deposits made on a mandrel as

a substrate may be difficult to withdraw because of shrinkage unless the mandrel is slightly tapered. A taper of approximately 2 percent is suitable in most cases. Continuously formed tube may be sawn into lengths by means of a flying saw after it has cooled in the inert or reducing atmosphere to such a temperature that subsequently oxidation in air is not deleterious.

To produce metal strips excellent results may be obtained with layers of up to about 0.5 inch, particularly from 0.01 to 0.375 inch thickness composed of particle sizes of the order of for example 20 microns thickness and 200 microns diameter. The porosity of the layers obtained in this way is usually of the order of 15 — 20 percent and the layers are quite coherent and strong and may be readily peeled from the substrate while still hot and subsequently hot worked. The very fine state of division of the deposited metal not only avoids difficulties normally associated with segregation of constituents, but can also act as an excellent starting point for the preparation of superplastic alloys. Facilities for cooling the substrate may be provided, if necessary, to ensure that the layer is sufficiently self-supporting at the point at which it leaves the substrate but frequently cooling is not required since the temperature of the deposited layer can be controlled by controlling the quantity of atomizing gas admitted to the chamber.

The deposited layer is normally removed from the substrate before being subjected to hot rolling or other means of compacting by hot working since this enables an equalization of temperature through the thickness of the layer to take place, although in certain embodiments of the invention to be described later this is not necessary. For most metals it is desirable that the "green strip" remain in contact with an inert or reducing gaseous environment up to the nip of the rolling mill or the corresponding part of any alternative compact means and this may be achieved by arranging that the chamber extends up to the compacting means. Indeed it is also preferred that when the reduced strip leaves the rolling mill and throughout its subsequent processing steps are taken to minimize the degree of oxidation of the metal. Normally it is desirable that the reduced strip should be non-porous, and in order to close the pores in the deposited strip a comparatively large reduction is required. Usually a reduction of 10 to 60 percent, for example about 30 percent is required to be produced by hot working. The phrase "hot working" is used to include any process involving the plastic deformation of a metal at a temperature above its recrystallization temperature which is usually from 0.4 to 0.5 of its melting point on the Absolute Temperature Scale.

The uppermost surface of the layer is frequently relatively rough in comparison with the surface which has been adjacent to the substrate and this may be reflected in the surface finish after hot working. An improvement of the surface in this respect may be obtained by coating a thin layer of metal powder on to the deposited layer before compaction. The powder may then be rolled into discontinuities in the original surface and so produce an excellent finish. Alternatively a strip whose surfaces have similar characteristics may be produced by depositing a plurality of coherent layers and welding them together by the action of heat and pressure. The method can also be used to produce strips of greater thickness than can be conveniently deposited in a single layer, and in this case the surface characteristics need not be similar.

This process may be conveniently carried out by passing the deposited metalliferous layers, while still hot, through a pair of rolls. In this way the welding and compacting steps can be carried out together.

In a preferred method of performing this aspect of the invention, the process is conducted continuously and metalliferous material is deposited on to two substrates in the form of drums, tubular rings or rolls rotating in opposite directions. The deposited layer is stripped off each substrate, usually while under an inert or reducing atmosphere, and the layers are allowed to come together in the nip of a rolling mill so that the two "sprayed" surfaces meet and the two surfaces adjacent to the substrate remain on the outside. The action of

the rolling mill is to pressure weld and compact the two layers to form a single strip.

An alternative procedure is to bring together the two layers on the rotating substrates in the form of drums, tubular rings or rolls and weld them by applied pressure between the drums, rings or rolls before the strip formed by welding is detached from the substrates. The advantage of this procedure is that the detaching of the strip from the rotating substrates is particularly easy and stripping knives need only be fitted to guard against accidental sticking to the substrates.

These methods have the advantage of allowing laminated composites to be made by depositing one or more different metals on each rotating substrate before welding and compacting. They also allow reinforcing or other materials such as metal or non-metallic strip, or additional metal spray or powder to be inserted between the two layers and compacted. Suitable parting materials and compounds may be inserted in the same way between the two layers to prevent welding over part of the strip. Such parting materials may take the form of patterns made of paper or other materials preventing welding. After compaction or subsequently further processing the unwelded parts within the strip may then be inflated pneumatically or hydraulically to form an interconnecting tubular or other structure. Stiffened strip may be produced by inserting honeycomb, corrugated or other stiffening material before it enters the nip of the compacting rolls.

Thin wall tubes are particularly difficult and expensive to make by conventional methods but excellent results have been obtained with the new process. To produce tubes a rotating mandrel may be used as a substrate. To ensure an even layer of metal, the atomizing jet is moved along the mandrel, or the mandrel may be moved in relation to the jet. The conditions of deposition and the properties of the layer are similar to those mentioned in the case of strip material. After coating the mandrel, the assembly is compacted by hot working which may be carried out by swaging or by tube rolling while still remaining in a protective environment or at a convenient temperature in air. The compacting operation also increases the internal diameter of the tube and allows it to be slid off the mandrel. The tube so produced may then be treated by conventional methods such as being reheated in a protective atmosphere to sinter and anneal before further processing.

Difficulties may be encountered in withdrawing the mandrels from the tubes after spraying or after compacting subsequent to deposition, when it is required to carry out the operation continuously. In this case, the process may be conducted by directing atomized particles of molten metalliferous material on to a substrate comprising a plurality of mandrels which are joined end to end and rotated so that a coherent layer of metalliferous material is deposited thereon. Preferably the process is carried out continuously, and the mandrels are passed through a chamber provided with nozzles for introduction of the metal particles. One or more nozzles may be used in the chamber. To ensure a rapid output it is desirable to have several nozzles which may be arranged both longitudinally and radially with respect to the mandrels. The radial, or near radial positioning of two or more nozzles is particularly effective as the impingement of the jets of particles causes them to spread out into a narrow band of high spray density along the length of the mandrel. Alternatively the spray may be deflected by any of the means described later in order to increase the spray density falling on the mandrel and ensure a low wastage of sprayed particles. The individual mandrels can be arranged to have screw or locking devices at each end so that they can be joined end to end on the ingoing side of the spraying chamber, and can be arranged to rotate. On emerging from the spray chamber after deposition of the metal particles the coated mandrels travel through a short tunnel directly to the compacting device. Prior to being compacted it is generally desirable to retain an inert or reducing atmosphere within the tunnel in order to avoid oxidation.

The coated mandrels while still hot, pass through the compacting equipment which may be one of several tube or rod

rolling devices. After compacting, the coated mandrels may be disconnected from one another and the tube stripped off.

The new process allows laminated tubes to be prepared with ease. Tubes lined and/or externally coated with a different metal have been prepared in the same combinations as in the case of strip by successive applications of a spray or a metal powder application before compacting. Moreover it is possible, by building up a thicker layer of the cladding or lining metal at the ends, to produce, for example, a steel tube lined with copper having solid copper ends.

The invention is illustrated in the accompanying schematic drawings of which:

FIG. 1 represents a longitudinal section of an apparatus for forming metal strip;

FIG. 2 is a cross section of FIG. 1 along the line II — II;

FIG. 3 represents a longitudinal section of an apparatus for forming metal tube continuously by deposition on to a surrounding reciprocating tubular substrate;

FIG. 4 represents a longitudinal section of an apparatus for forming metal strip continuously by deposition on to two rotating tubular rings;

FIG. 5 is a partial transverse section of the apparatus of FIG. 4;

FIG. 6 represents a longitudinal section of an apparatus for forming metal strip continuously by deposition on to two rotating drums, stripping and subsequently compacting in a rolling mill;

FIG. 7 represents a longitudinal section of an apparatus for semi-continuously forming metal tube by depositing on mandrels;

FIG. 8 shows a longitudinal section of part of an apparatus for producing metal strip by deposition on to a single rotating metal drum; and

FIGS. 9 to 15 show in side elevation various devices for deflecting the metal spray in the production of narrow strip, bar or rod material.

Referring to FIGS. 1 and 2, the substrate on which the metal coating is to be deposited is a stainless-steel endless band 1 driven by rollers 2,3 in the anti-clockwise direction. During its forward movement over support rollers 4 the band 1 passes below an atomization chamber 5 of water-cooled mild steel construction. The walls 6, 7 of the atomization chamber 5 are constituted by a rectangular housing in which atomization and spraying is effected. The band 1 passes through suitable end seals in the front and rear walls 6, 7 and thus provides the floor of the chamber 5.

The top 8 of the atomization chamber 5 is formed with two inlet apertures cooled by means of water jackets 9 each being shaped to receive an annular jet 10 through which nitrogen may be passed. Nitrogen is supplied through a main inlet pipe 11 joined to manifolds 12 which run across the top of the chamber 5 and feed the jets by means of connecting tubes 13. Additional gas connections from the manifold to the chamber are made through pipes 14, 15 and pipes 16 (FIG. 2) to provide gas curtains at the end and side walls respectively of the chamber 5 to prevent accretion of metal thereon. The sides 17, 17a of the chamber 5 extend downwardly below the level of the band 1, and terminate in exhaust ports 18, 18a through which excess nitrogen and metal spray are removed. The top 8 of the chamber is provided with a nitrogen outlet 19.

Supported over the atomization chamber 5 is a refractory lined molten metal reservoir 20 the bottom of which is formed into two projecting outlets 21 shaped at their lower extremities to fit closely to the jets 10. Stoppers (not shown) are provided to seal the outlets 21 when not in use, and to control the flow rate.

Connected to the atomization chamber 5 in the downstream direction is an after-treatment chamber 22 in water-cooled mild steel construction which is conveniently formed as an extension of the chamber 5. The chamber 22 is provided with a hopper 23 for metal powder which is supported in the top of the chamber 22 and around the outlet to the hopper 23 is an annular passage 24 for receiving nitrogen from a downward

extension 25 of the manifold 12. The chamber is provided with a nitrogen outlet 26 and baffles 27 for retaining entrained metal powder inside the chamber 22. Shielded thickness gauges 28 are located at the point where the band 1 leaves the atomization chamber 5.

The after-treatment 22 extends up to the nip of the rolls 29 of a rolling mill so as to maintain a protective nitrogen atmosphere around the metal strip being formed. A stripper blade 30 is located close to the forward driving roller 2 in order to remove the green strip from the band 1 and a number of small guide rollers 31 lead the stripped product into the nip of the rolls 29.

Referring now to FIG. 3, the apparatus comprises a stationary head 40, fitting within a tubular substrate 41 which is arranged for reciprocation in the vertical direction by means of a stirrup 42. Fitted into a central aperture in the head 40 is a rotating blast bowl atomizer comprising a rotating annulus 43 running in bearings 44. The annulus is provided with a refractory tubular lining 45 which is flared out at the lower end. The annulus 43 is supplied with nitrogen through a stationary manifold 46. The stationary head 40 is provided with an off-take 47 for nitrogen gas. Metal is supplied to the axial passage in the atomizer from a tundish 48.

The reciprocating member 41 is connected by means of bellows 49 to the stationary tubular lower portion 50 of the apparatus which is provided with a nitrogen in-take 51 and off-take 52.

In operation, liquid metal flows from the tundish 48 through the atomizer and outwardly at the lower flared end of the lining 45, where it meets a jet of nitrogen gas passing out of the annulus 43 which causes the liquid metal to be sprayed outwardly against the substrate 41 where it forms a continuous and coherent tubular layer. The substrate 41 is reciprocated vertically as spraying proceeds and eventually a solid and self-supporting tube is built up and removed continuously from the lower end of the apparatus. As the tube shell is withdrawn it is hot-rolled internally and sawn into lengths by means of a flying saw (not shown).

Referring now to FIGS. 4 and 5 metal and nitrogen enter the nozzles 61 and the atomized metal is deposited on to steel rings 62 which rotate in the direction shown. The metal deposits on the two rings meet at 63 where a pair of rolls 64 which are hydraulically loaded, supply the pressure to weld together and plastically deform the two deposits to form a single strip 65. The rolls are driven by a conventional rolling mill drive and supply the torque required to rotate the two rings. The rings are further guided and supported by four rollers 66 and the nozzle chambers are arranged to float to allow for thermal expansion of the rings. Two knives 67 are positioned to ensure that the strip does not adhere to the substrate. The rings are cooled to operating temperature by water jets at 68 cleaned by brushes at 69 and dried by means of an air blast at 70. Off-take of nitrogen and surplus powder from the main chambers 71 is made via the manifolds 72. Additional nitrogen is admitted at 73 for further cooling of the deposit on the ring and to maintain relative freedom from metal powder in the cooling chamber 74. Both the manifolds 72 and the cooling chamber 74 are arranged to seal beneath and around the ring 62. The gases leave the cooling chamber by the ports 75. If required reinforcing or other material may be introduced into the confluence of the deposit at 63 through an opening which can be provided at 76. The rings 62 can, for example, be from 10 to 30 feet in diameter, enabling a high output of strip to be attained.

An alternative apparatus is shown in FIG. 6 which is similar in many respects. The deposition procedure is similar but is made on to the surfaces of two large drums 77 which are rotated in opposite directions. The deposit is stripped from each drum by means of knives 78 and converges at 79 where the rolls 80 of a hot rolling mill weld together and plastically deform the two deposits. The rolls 80 are driven at a speed to match the peripheral speed of the drums. A short tunnel 81 seals on to the rolls of the rolling mill to avoid ingress of air to

the strip before welding. All other aspects of the equipment are similar, and reinforcing and any other material may be added through an opening provided at 82.

Referring now to FIG. 7, liquid metal and high pressure nitrogen are fed into the atomizing nozzles 91 which are all arranged longitudinally with respect to the mandrel and the metal is deposited on to a mandrel 92 which is about 25 feet in length. Nitrogen and overspill powder are taken off at 93. The mandrel is moved forward through the chamber 94 by means of clamps 95 and 96 which are free to rotate but can be attached when required to a chain (not shown) which moves continually in the direction of movement of the mandrels. In FIG. 1 clamp 95 would be fixed to, and clamp 96 would be free of the chain.

The coated mandrel moves through the chamber 94 and then through a short tunnel 97 which terminates close to the reeling machine 98 which compacts the deposit at the same time as it expands the internal diameter of the tube slightly to release it from the mandrel. The tunnel 97 ensures that the inert or reducing atmosphere is retained around the deposit until it issues from the reeling machine. The reeling machine rotates the mandrels in such a way that when they are fed along the roller table 99 they automatically screw together and lock tightly on the ingoing side. Similarly by clamping an outgoing mandrel on the run-out table 100 the bar carrying the tube is unscrewed and detached. To facilitate the marking of the joints in the mandrels through the covering tube a short length near the end of each mandrel is slightly tapered as shown in the drawing at 101. The advantage of this procedure is not only that the mandrel joints are clearly shown, but the deposit in those regions is not compacted. It is therefore readily removed and facilitates the stripping of the tube from the mandrel. Free rotation and alignment of the mandrels is achieved by the use of two ball races 102 loosely fitting the mandrel. After use the mandrels are cooled and returned to the ingoing side of the equipment.

Referring now to FIG. 8, the substrate on which the metal strip is to be deposited is a metal drum 110 driven in an anti-clockwise direction. An atomization chamber 111 having sprays 112 is arranged above the drum. A small roll 113 running at the same or lower peripheral speed than the drum is located beyond the deposition chamber. The small roll bears against the drum and the differential speeds of the rolls facilitates the removal of the deposited strip by the stripping knife 114. The roll is sealed on to the ducting 115 which contains the nitrogen atmosphere around the strip until it passes through the rolling mill 116 and is wound on to a reel 117.

An important aspect of the process is the control of the distribution of spray in the deposition chamber by deflection means. Mention has been made of the use of gas curtains as a means of deflecting the spray from the walls of the chamber and thus avoiding accretions. The use of suitably inclined sprays has also been mentioned. The distribution of spray can further be modified by deflecting with further jets of gas or by suitably placed surfaces inclined at a relatively low angle to the direction of flight of the particles.

The distribution may also be altered by superimposing a magnetic field by means of suitably wound solenoids which will deflect the particles in flight. This latter arrangement is, of course, operable with both ferrous and non-ferrous metals.

A particularly important use of the principle of deflecting particles in flight is in the use of an "under spray" technique for producing narrow strip, bar or rod as compared with the more usual "overspray" technique for wide strip. In this case the substrate is contoured to the cross section required and the spray of particles is deflected into the contoured area. In this way the spray is concentrated in the area required, losses are reduced, thickness is increased and the speed of operation is increased. In FIG. 9, which is a cross section in the plane of the axis of rotation of one wheel of a twin wheel equipment, deflection of the spray is caused by stationary smooth water-cooled surfaces. In FIG. 10, also a section of a twin wheel equipment, a circular rod is formed by the rolling together of

two halves, one of which is shown. In this case a venturi effect is brought about by a narrowing of the deflecting walls to provide a high spray density where required. Part of the carrier gas is returned to the top of the venturi from where it flows over the deflecting walls.

FIG. 11 shows a longitudinal section and FIG. 12 a vertical section of a single wheel machine in which moving deflectors 120 rotate independently on the same axis as the wheel. The speed of rotation can be the same as that of the wheel or different, either in the same or a reverse direction. This arrangement has the advantage of enabling the deflectors to be cooled and cleaned at positions 121 and 122.

A different design for providing a concentration of spray is shown in FIG. 13 which is a cross section of a twin wheel machine making a diamond shaped bar from single nozzles. The cross section is taken in the plane of the axis of the wheel. It shows two rotating drums 130 which drag a boundary layer of gas along the surface of the drum 131 thus preventing adherence of spray. Cooling and cleaning of the drums is carried out at positions 132 and 133. Most of the carrier gases of the spray exits at 134 but some returns at the two ends of the equipment (not shown). This arrangement has the advantage of enabling the deflecting walls to be cooled and cleaned during operation of the equipment.

FIG. 14 is a cross section of one wheel of a twin wheel machine for producing square bar in which the facility for deflecting the spray is made an integral part of the wheel. FIG. 15 shows the apparatus in longitudinal section. Smooth walled V-grooves are machined in the rim of the wheel to present a fairly low angle, in this case about 45°, to the spray. The sprayed particles are deflected down to the bottom of the groove which may have a somewhat rougher surface than the walls. A coherent deposit builds up rapidly until the grooves are filled. The grooves in the two wheels match one another so that, in operation, several contiguous square sections are produced. The individual square bars are then separated by slitting cutters after which they are fabricated by normal bar or rod methods. One advantage of the procedure is that it allows central reinforcing or strengthening material to be added at 140. For instance, a steel wire may be added to strengthen a low strength metal conductor bar.

In all the cases given above a variety of sections can be made by suitably contouring the periphery of either one or both wheels, drums or rolls.

I claim

1. A process for the fabrication of metal in shapes of long length and relatively thin cross section which comprises depositing a plurality of coherent layers of metal on a plurality of substrates by directing streams of gas-atomized particles of molten metal onto the substrates to coalesce and form coherent layers of metal on the substrate; and hot working the metal layers together by the action of heat and pressure to weld the layers together and form a single layer while the metal is at a temperature above its recrystallization temperature as a result of its initial heating to molten metal.
2. A process according to claim 1, in which the substrates are moved relative to the particle streams so that continuous layers of metal are deposited on to the substrates.
3. A process according to claim 1, in which the molten metalliferous material is atomized in an inert or reducing gas.
4. A process according to claim 3, in which the gas is nitrogen, hydrogen, a flue gas, a blast furnace gas, or mixtures thereof.
5. A process according to claim 3, in which the deposited layer is maintained in an atmosphere of an inert or reducing gas until it is compacted by hot working.
6. A process according to claim 1, in which compaction of the layer of metal is carried out by hot rolling.
7. A process according to claim 1, in which an additional component which is immiscible with or insoluble in the molten metal is directed on to the substrates separately so that it becomes incorporated into the deposited layers to form a composite material.

8. A process according to claim 7, in which the additional component is lead, a ceramic powder, or a fiber.

9. A process according to claim 7 in which the additional component is directed on to the substrates at an oblique angle to form a composite material in which the additional component is partially or completely aligned in one direction.

10. A process according to claim 1, in which is carried out by depositing the particles of molten metal on to a pair of rotatable substrates rotating in opposite directions, stripping the deposited layers from the substrates, bringing the deposited layers together so that the sides of the layers adjacent to the surfaces of the substrates are outermost, and rolling the layers together in a rolling mill.

11. A process according to claim 1, which is carried out by depositing the particles of molten metal on to a pair of rotatable substrates rotating in opposite directions, bringing the deposited layers together while still on the substrates, and welding the layers together by the action of heat and pressure between the substrates to form a single layer.

12. A process according to claim 1, in which successive layers of different metals are deposited on the substrates to produce a laminate having successive layers of different metals.

13. A process according to claim 1, in which reinforcing material is inserted between successive layers of deposited metal.

14. An apparatus for the fabrication of metal in shapes of long length and relatively thin cross section by deposition of molten metal on to a substrate and subsequent removal of the shaped metal article therefrom, which comprises

a chamber provided with means for producing a stream of gas-atomized particles of molten metal and for directing the particles on to a substrate located within the chamber in such a manner that coalescence of the particles occurs to form a coherent layer,

means for hot working the deposited layer while the metal is at a temperature above its recrystallization temperature, means for withdrawing the deposited layer from the chamber, and

means for imparting a reciprocatory motion to the substrate in a line parallel to the direction of withdrawal of the deposited layer.

15. An apparatus for the fabrication of metal in shapes of long length and relatively thin cross section by deposition of molten metal onto a substrate and subsequent removal of the shaped metal article therefrom, which comprises

a chamber provided with means for producing a stream of gas-atomized particles of molten metal and for directing the particles onto a rotatable drum substrate located within the chamber in such a manner that coalescence of the particles occurs to form a coherent layer,

a peripheral roll located adjacent the rotatable drum and rotatable at a slower peripheral speed than the drum to facilitate the removal of the deposited layer from the drum by a stripping knife located adjacent the drum,

means for hot working the deposited layer while the metal is at a temperature above its recrystallization temperature as a result of its initial heating to molten metal, and

means for withdrawing the deposited layer from the chamber.

16. An apparatus for the fabrication of metal in shapes of long length and relatively thin cross section by deposition of molten metal, which comprises

a chamber provided with means for producing streams of gas-atomized particles of molten metal and for directing the particles onto a plurality of substrates located within the chamber in such a manner that coalescence of the particles occurs to form coherent layers on the substrates, means for welding the deposited layers together,

means for withdrawing the combined layer from the chamber, and

means for hot working the combined layer while the metal is at a temperature above its recrystallization temperature as a result of its initial heating to molten metal.

17. An apparatus according to claim 16, comprising a pair of rotatable substrates rotatable in opposed directions, stripping means to strip the deposited layers from the substrates, means for bringing together the layers so that the surfaces of the layers adjacent to the surfaces of the substrates remain on the outside, and means for rolling the layers together to weld and hot work the combined layers while still hot.

18. An apparatus according to claim 16, comprising a pair of rotatable substrates rotatable in opposed directions, and means for applying pressure between the substrates so that the layers deposited thereon are welded together and hot worked while still hot.

19. An apparatus according to claim 16, in which the stream of gas-atomized particles is produced from nozzles in the wall of the chamber arranged longitudinally and transversely with respect to the substrates.

20. An apparatus according to claim 14 in which said substrate is tubular and arranged for reciprocation in a vertical direction, and the stream of gas-atomized particles is produced by a rotating blast bowl atomizer located within said substrate.

21. An apparatus for the fabrication of metal in shapes of long length and relatively thin cross section by deposition of molten metal onto a substrate and subsequent removal of the shaped metal article therefrom, which comprises

a chamber provided with means for producing a stream of gas-atomized particles of molten metal and for directing the particles onto a substrate located within the chamber in such a manner that coalescence of the particles occurs to form a coherent layer, the substrate comprising a rotatable mandrel movable longitudinally through said chamber,

means for hot working the deposited layers while the metal is at a temperature above its recrystallization temperature as a result of its initial heating to molten metal, and means for withdrawing the deposited layer from the

chamber.

22. An apparatus according to claim 21, in which the mandrel is provided with a taper of about 2 percent.

23. An apparatus according to claim 21, in which the substrate comprises a plurality of mandrels which are joined end to end and rotatable together so that a coherent layer of metal is deposited thereon.

24. An apparatus according to claim 23, in which the mandrels are provided with screw or locking devices at each end so that they can be joined end to end on the ingoing side of the chamber, and separated after hot working of the deposited layer to produce a metal article of the desired length.

25. An apparatus according to claim 21, in which the chamber is provided with nozzles for producing streams of gas-atomized particles arranged longitudinally and radially with respect to the mandrel.

26. An apparatus according to claim 16, in which deflection means are provided for controlling the distribution of the particles on the substrate.

27. An apparatus according to claim 26, in which the deflection means comprises a gas curtain.

28. An apparatus according to claim 26, in which the deflection means comprises a surface inclined at a low angle to the direction of flight of the particles, or a solenoid-induced magnetic field.

29. An apparatus according to claim 16, which is provided with means for feeding a releasing agent as a thin film on to the surface of the substrate.

30. An apparatus according to claim 14, which is provided with means for feeding a releasing agent as a thin film onto the surface of the substrate.

31. An apparatus according to claim 14, wherein the substrate is moved with a reciprocating cycle in which the substrate is moved in the direction of withdrawal of the deposited layer at a slow speed and then moved in the reversed direction at a faster speed.

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