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(56) Documents cited
GB 1605035 **US 4374789**

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C7F
C7X
C1M
B2F
B2L
B3F

(54) Casting and coating with metallic particles

(57) Metallic droplets in liquid, solid or partially solidified form are deposited onto a substrate to produce cast or coated articles by utilizing the Coanda Effect to draw one stream of gas toward another stream of gas flowing over a surface and introducing molten metal between the two gas streams such that the molten flow is broken into droplets. In the embodiment primary fluid flows through slit 50 over Coanda surface 30 and entrains environmental fluid. Metal stream M is introduced into entrainment zone P through slits 70 in tundish 80 and the resulting droplet spray deposited on a substrate.

FIG. 2.

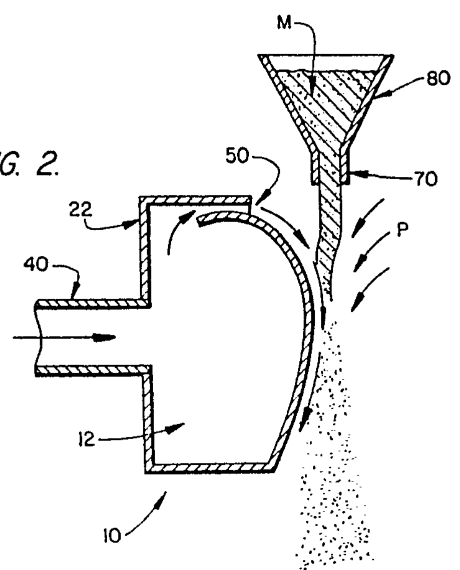

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FIG. 1.

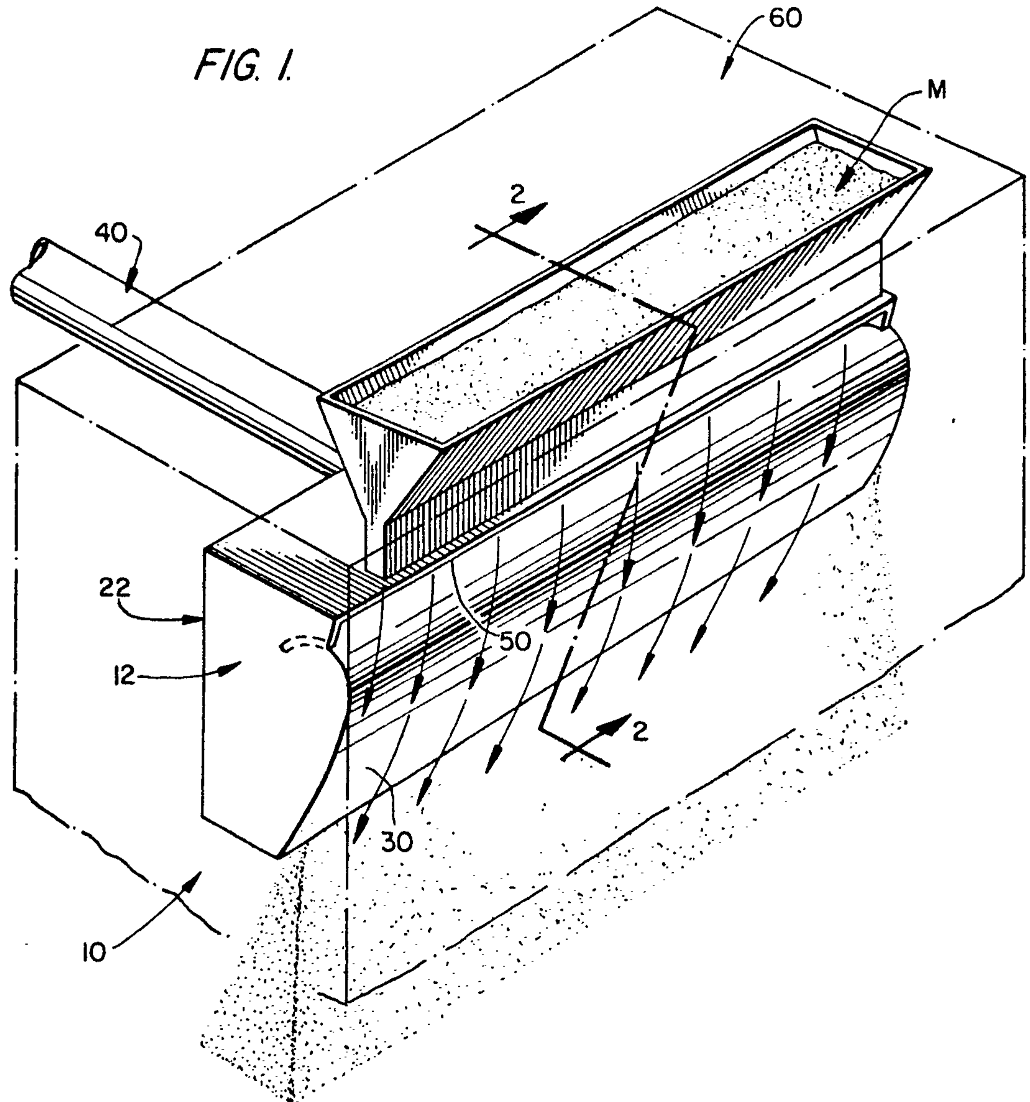


FIG. 2.

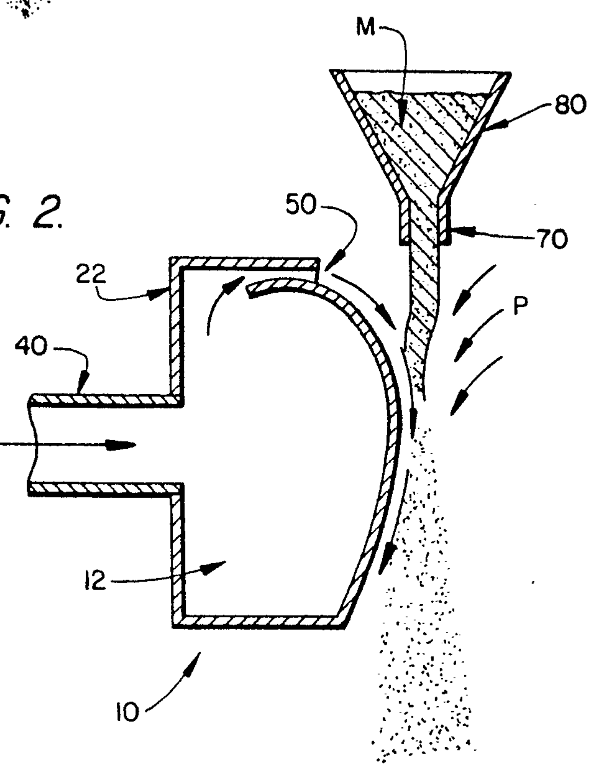


FIG. 3A.

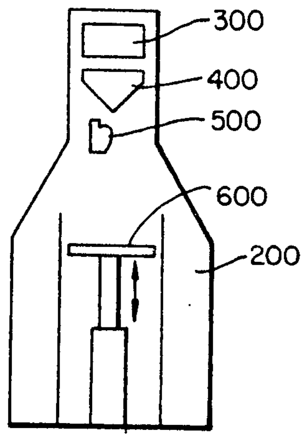


FIG. 3B.

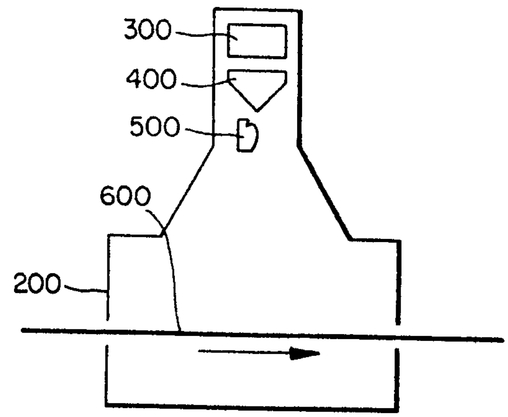


FIG. 4.

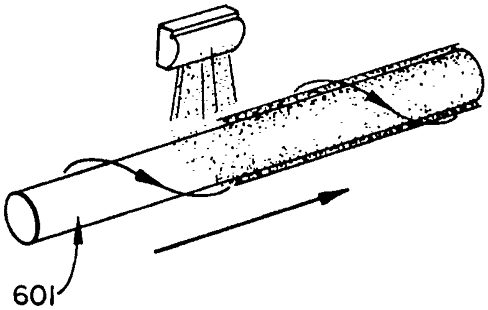


FIG. 5.

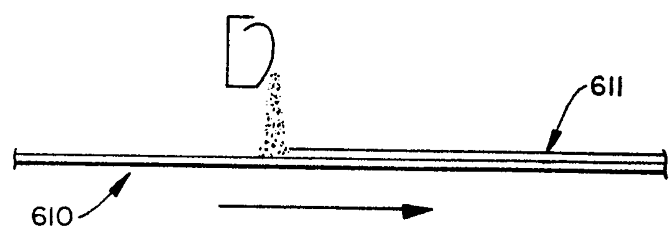
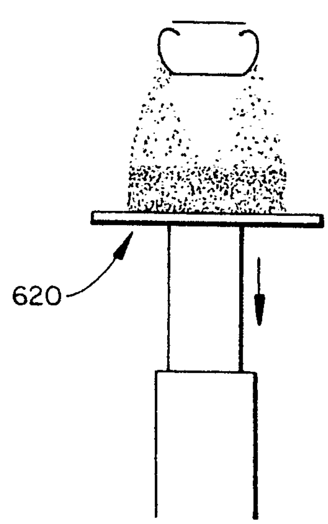


FIG. 6.



SPECIFICATION

Casting and coating with metallic particles

The present invention relates to processes of coating, consolidating and casting metal particles produced by the Coanda Effect onto a substrate or collector/holder, and to apparatus used for effecting such processes.

Composite structures are often prepared in which a coating of special-purpose metallic material is applied to a substrate of a base metal to become an integral structure which possesses desirable surface characteristics. Hard coating for severe wear applications is a typical use which requires application of special surfaces by means other than plating. Techniques presently available are very slow and expensive.

Metallic coating processes other than plating include thermal spray coating, chemical vapor deposition, vacuum coating, sputtering, ion plating and ion implantation. These are described in Volume 5 of the 9th Edition of the *Metals Handbook*, published by the American Society for Metals.

Production of super alloys with superior properties and fineness of micro-structure is carried out by a variety of melting, powder metallurgy and consolidation techniques, which include vacuum induction melting, vacuum arc remelting, powder metallurgy, hot isostatic pressing, extrusion, forging, and the VADER process.

These processes are typically expensive and involve complex operations since the severe requirements imposed upon these super alloys require extreme purity and the virtual elimination of inclusions. Many of the most extreme applications are considered to be unachievable by existing powder metallurgy techniques. Recent developments, such as the VADER process, eliminate the powder manufacturing step by the consolidation of semi-liquid droplets (above the solidus temperature, but below the liquidus temperature), which are generated from two consumable electrodes. This operation is considered to be a likely improvement in production of super alloys required for severe applications. This process is inherently more conserving of energy and capable of producing fine-grained super alloy material which is vertually free of inclusions. The process is, however, a slow one and its cost may preclude its use in all but the most special applications.

There is, therefore, a need for a coating process and apparatus which will produce coatings having special characteristics which are faster and cheaper than those known today. Further, there is a need for a process of producing these special super alloys free of impurities and weaknesses resulting from the prior art processes. There is also a need for a process that will be less expensive and faster than the prior art processes, and also a need for apparatus to effect this process.

In accordance with the present invention, it has been found that metal coatings can be generated, applied and integrated with metallic substrates to form composite structures, using the Coanda Effect to produce said coatings.

In accordance with one aspect of the present invention, there is provided a process for producing a metallic article, which comprises flowing a first fluid along a Coanda surface and locating a second fluid adjacent to the Coanda surface with the flow of the first fluid influencing the second fluid to flow in a direction which intersects the first fluid, flowing a molten metal adjacent the Coanda surface between the first and second fluids, flowing the first and second fluids and the molten metal to an intersection position whereat the first and second fluids intersect and intermix to break up the molten flow into metallic droplets, and depositing the metallic droplets onto a substrate to produce a metallic article.

The coating is formed in the present invention by deposition of a high-velocity spray of molten metal, or mixtures of metals, upon a substrate, causing a build-up of coated material which is, in itself, homogeneous and becomes integrally bonded to the substrate. Very high speeds of coating are possible because of the application of a Coanda Effect generator as a spray deposition device. The process may interact with a suitable melt process for generation of metal particles to be consolidated upon a substrate and become an integral structure which possesses desirable qualities of surface. The process utilizes a device capable of generation of molten metal droplets of various size and permits the introduction of various gaseous atmospheres to impart specific properties to the droplets generated. This atmosphere may also be used as a carrier for other modifying elements in particle or liquid form.

In addition, the present invention can produce metal castings having fineness of grain structure, at a much faster rate than previously known in the art. The present invention combines the use of the Coanda Effect to produce metal particles which can be cast into solid forms.

The use of the Coanda Effect for producing and recovering discrete metal particles by quenching is set forth in our U.S. Patent No. 4,374,789, but has nowhere been described or suggested for the purposes set forth herein.

The Coanda Effect can be described as the tendency of a gas or a liquid coming out of a jet to travel close to a wall contour, even if the wall curves away from the axis of that jet. In so doing, a negative pressure is created (in a manner similar to an airplane wing) which causes adjacent environmental fluid to be entrained. This entrainment phenomenon results in severe turbulence at the boundary layer. If a third fluid is introduced into the entrainment zone, it becomes a part of the system and is violently involved by the force of the entrainment. If this introduced fluid is a molten metal stream, the stream is disintegrated into a spray by the turbulent gases which is discharged from the foil surface.

The present invention, in another aspect, includes an apparatus for producing a metallic article, which comprises means for producing a Coanda Effect, means for providing a source of molten metal to be entrained in the Coanda Effect, and means for receiving metal droplets produced thereby to form a metallic article. This apparatus is simple and easy to maintain.

The main elements of the Coanda Effect device used herein may comprise a chamber into which fluid (gas) may be forced under pressure; a slit of appropriate size to permit escape of the fluid at the desired velocity; and a foil surface adjacent to the slit to which the primary fluid may attach and induce the entrainment phenomenon discussed above.

A wide range of process output can be achieved by exercise of the many variables available in the device and process of the invention.

The particles produced by the Coanda Effect device can have a single-phase, either molten or solid, or they can have two-phases resulting in a mushy, partially solidified, particle. These particles are deposited on substrates or in molds to produce cast products. When desired, as when solid particles are produced, they can be further formed by compaction.

A major advantage of the Coanda device is its inherent speed and the ease in which the device can be scaled up or extended dimensionally. The production rate of these particles is very high, thereby out-performing the prior art methods of vacuum arc re-melting, powder metallurgy and VADER process in both speed and economy of production. This result further eliminates many of the subsequent treatments of the cast product, except where solid particles are produced. The particles produced for casting can be made with various apparatus, depending on the configuration of the cast product.

Further, the particles produced can have various qualities and characteristics imparted to them during production due to the uniqueness of the apparatus and which will result in innumerable products.

Furthermore, this invention includes apparatus to generate a high rate of molten metal droplets, either single-phase (molten), or, preferably, two-phase (mushy) from a liquid stream of appropriate geometry; and, subsequently, consolidate in a variety of forms so as to achieve a solid mass of extreme fineness of micro-structure with minimum contamination of the solid by non-metallic particles. This method embodies the application of the Coanda Effect to generate the molten-metal droplets. Of course, the shape of the cast metallic object can be altered by use of appropriate placement, geometrics, and configuration of the generation device and associated collection surfaces. Billets or ingots can also be produced from a device which includes a collector which moves away from the Coanda generating device.

Another feature of the invention is the production of a plate or strip of cast material from a linear Coanda generator associated with a surface moving transversely thereto. This arrangement can be used in material coating processes which would include hard faced alloys.

Other apparatus can be used to coat elongated pipe by spraying such pipe which is advanced as well as rotated during the coating process. Again, a linear Coanda generator can be used, or circular types, or other various configurations. In some applications, the pipe can be preheated so that the deposited metal particles will bond therewith. Such applications can be used for hard facing rolls. Corrosion resisting coatings for pipe and other components can also be applied by this process and apparatus for use, for example, in the chemical processing industry.

A further important feature of this invention is to generate, apply and integrate a coating of desired metallic particles with a metallic substrate to form a composite at the junction thereof. With such structures, the coating is developed by deposition of a molten metallic spray upon a substrate causing a buildup of coated material which is, in itself, homogeneous and integrally bonded to the substate. With such apparatus and processes, very high speeds of coating are possible.

Another embodiment provides an array of Coanda generator devices in combination for the desired coating and/or depositing on the collector surface. Devices in various forms can buildup an ingot by spraying in various directions.

The invention is described further, by way of illustration, with reference to the accompanying drawings, wherein:

Figure 1 is a perspective view of one embodiment of a Coanda Effect device used in the present invention;

Figure 2 is a sectional view taken along line 2-2 of Figure 1;

Figures 3A and *3B* are schematic diagrams of apparatus configurations used in the present invention, Figure 3A showing a retraction-type holder/collector and Figure 3B showing a linear moving holder/collector; and

Figures 4, 5 and *6* show a variety of collector/holder configurations usable in the present invention.

Referring to the drawings, shown in Figure 1 is a Coanda device 10 comprised of a chamber 12 enclosed by a housing 22 in which one side thereof is a curved surface 30 forming a Coanda surface. The curvature may be designed to meet the requirements of individual application. The housing contains an opening 40 through which the primary fluid is introduced under the required pressure to achieve the appropriate flow velocity through slit 50 in order to effect attachment of the primary fluid to the curved surface 30.

An environmental or second fluid, which may be enclosed by an outer chamber 60, will be entrained by the primary fluid which results in severe turbulence at the boundary layer.

A third fluid M introduced into the entrainment zone P shown in Figure 2 becomes a part of the system and is violently involved by the forces of entrainment. When this introduced third fluid is a molten metal stream, it is disintegrated into a spray which is discharged from the foil surface 30. Such metallic stream M may be introduced into the entrainment zone P through holes, slits or other orifice configurations 70 which permit this flow from a tundish 80 which holds the metal supply.

The tundish 80 may be configurated to fit the application (deposition configuration) and may be designed to dispense molten material in a straight line, a circle or any other configuration which the application requires. The finer the stream of metal flow, the finer and more consistent the resulting droplet spray. Therefore, the molten metal may be dispensed, for example, through holes of various diameters and slots.

As with the tundish 80, the Coanda device 10 might be designed in a wide variety of configurations. It may be straight line, circular, square, irregular, helical, or any other configuration which satisfies the application.

The curved surface 30 of the device 10 may be a part of the device chamber 12 or may be separated from the chamber 12 if required to permit added flexibility in altering spray direction. By adjustment of the foil attitude, the direction of the spray may be altered to achieve deposition and directions other than straight down.

Size of the slit 50 may be adjusted for desired effect upon entrainment or velocity and volume of escaping primary fluid for certain conditions. The location of the slit 50 with respect to the curved surface 30 provides another variable which may be utilized to meet primary fluid velocity and entrainment characteristics required for a given application. One skilled in the art will know how to adjust the variables to their particular demands.

The primary fluid, which is usually gas, may be introduced into the chamber 12 at various pressures which achieve primary fluid flow required for specific applications.

The temperature of the primary fluid may be adjusted as required in order to retard or accelerate the cooling effect upon the process. Likewise, temperature of the metal supply may be adjusted to prolong or shorten the time required for cooling of the particles or droplets.

As stated above, the Coanda-type devices of the invention are not only capable of potentially high deposition rates, far in excess of conventional thermal-spray methods, but have the unique ability to add elements, chemical compounds of either a ceramic or metallic type; these additions are entirely independent of thermodynamic limitations.

These inert or chemically active particles can be added to the alloy at the moment of solidification. In some instances, for example, it may be desirable to inject small amounts of a chemically-active gas to the solidifying droplets. This feature might be especially appealing for the generation of new creep-resistant aluminum alloys containing thermally-stable oxide dispersoids. Further, large volume fractions of carbides, borides or silicides might be incorporated in high speed steels for additional wear resistance and improved cutting performance. It is possible to add these oxides, carbides, borides or silicides to both ferrous and non-ferrous metals as, for instance, aluminum, titanium, zirconium, iron and nickel-based alloys.

The flexibility of the Coanda deposition process offers a wide variety of alloy design and consolidation opportunities. For example, as mentioned previously inert or chemically active particles can be entrained or added to the gas stream emanating from the slit and subsequently be incorporated into the liquid droplets without excessive segregation or clustering. Large volume fractions of hard carbides, borides or silicides may be added to high alloy steels to enhance the wear and abrasion resistance of clad plates for mining or earth-moving equipment.

The inherent velocity of this system permits the required high droplet impact speed and disintegration into extremely fine droplets. Combination with other technologies, such as plasma arc, may be employed to enhance the process.

The apparatus and process for both casting and coating systems of the present invention may include, as seen in Figures 3A and 3B, five basic components: a chamber 200, a furnace 300, a tundish 400, a Coanda generating device 500, and a collector 600. A chamber 200 is required for both embodiments. The actual physical arrangement of the respective chambers 200 differs because of the differences in movement of the collector 600. Of course, the preferred configuration of the chamber 200 depends upon the specific application and use of the disclosed processes, and can vary from a single purpose chamber designed and built for a specific type of casting, or ingot buildup, to a general purpose chamber which is capable of handling a variety of different applications. However, certain basic requirements are necessary for any of the chambers. The chambers 200 are required to contain and effect the overall process and should be capable of permitting accurate and precise atmosphere control, and must be sized and shaped to accommodate the various configurations to be cast and/or coated.

The furnace element 300 will depend upon the metal material involved, the types of gases used, the degree of temperatures required, what atmospheric control must be effected, and the like. A number of known metal melting techniques can be used and furnaces to effect same as already known in the metallurgical art can be satisfactorily adapted for the furnace structure of the present invention.

Figure 4 shows a collector/holder arrangement wherein an elongated pipe 601 is spray coated by a suitable Coanda generating device. The pipe can be rotated by means not shown and moved in a lateral direction with respect to the Coanda device as indicated by the arrows in the drawing.

Figure 5 shows another type of collector/holder comprising a flat, linearly moving surface or substrate 610 moving in the direction of the arrow by means not shown. A coating or casting 611 is deposited thereon by a suitable Coanda device.

Figure 6 shows, in schematic form, a retracting-type holder/collector 620 for depositing casting-type ingots or billets by means of a Coanda device. In this case, the Coanda device is of a circular nature. Objects may be cast to specific shapes by providing the appropriate mold form into which the spray particles may be deposited.

As can be seen by the above-described specific embodiments, the possible combinations and variations of collector/holders are quite large in number, and the above-described embodiments are not to be considered limiting, but merely as illustrative examples of ones that may be used with the present invention.

The primary and secondary fluids usually are gases. As stated above, various mixes of gases can be used to achieve certain desired effects, and, of course, additional liquids, gases, or even solids, can be added to these gases for changing the composition thereof.

The invention described herein has been used to produce particles of various metals, such as lead, tin, cast iron and stainless steel (300 series). It has been used to coat cast iron upon a stainless steel substrate to achieve a fully integrated interface. Tin powders have been produced in the range as small as several microns and suitable for compaction as has stainless steel powder also suitable for compaction.

Some typical Examples showing the use of the present invention are set forth below. These Examples are merely illustrative and are not to be interpreted as setting forth the metes and bounds of the present invention.

Example I
Production of tin powder

Foil:	0° attitude
Slit:	Oriented 30° from 0 on curved foil surface
Slit Opening:	0.012″ (0.031 cm)
Material:	Sn
Temperature of Sn:	650°F (345°C)
Primary Fluid:	N_2 (at room temperature)
Chamber Pressure:	50 psi (345 kP)
Secondary Fluid:	N_2 (at room temperature)
Molten Stream Orifice:	1/8″ (0.32 cm) internal diameter
Drop Distance From Orifice to Slit:	3/8″ (0.95 cm)

Example II
Cast iron on stainless steel

Foil:	20° attitude
Slit:	30° from 0 axis on foil
Slit Opening:	0.008″ (0.020 cm)
Material:	Cast iron coating/stainless steel substrate
Temperature of Iron:	2650°F (1450°C)
Primary and Secondary Fluids:	N_2 (at room temperature)
Chamber Pressure:	50 psi (345 kP), 90°F (33°C)
Molten Stream Orifice:	1/8″ (0.32 cm) internal diameter
Drop Distance From Orifice to Slit:	2″ (5.1 cm)
Drop Distance (Foil to Substrate):	about 12″ (about 30 cm)
Cast Coating:	1/8″ to 1/4″ (0.32 to 0.64 cm)

In summary of this disclosure, the present invention provides a novel procedure for depositing metal droplets produced by the Coanda Effect onto a substrate to produce a metallic article. Modifications are possible within the scope of this invention.

CLAIMS

1. A process for producing a metallic article, which comprises flowing a first fluid along a Coanda surface and locating a second fluid adjacent to the Coanda surface with the flow of the first fluid influencing the second fluid to flow in a direction which intersects the first fluid, flowing a molten metal adjacent the Coanda surface between the first and second fluids, flowing the first and second fluids and the molten metal to an intersection position whereat the first and second fluids intersect and intermix to break up the molten flow into metallic droplets, and depositing the metallic droplets onto a substrate to produce a metallic article.

2. A process as claimed in claim 1, in which the metallic droplets are deposited on the substrate to produce a coated article.

3. A process as claimed in claim 1, in which the metallic droplets are deposited on a collector constituting the substrate to produce a cast shape.

4. A process as claimed in any one of claims 1 to 3, in which the droplets when deposited on the substrate are in a liquid state.

5. A process as claimed in any one of claims 1 to 3, in which the droplets when deposited on the substrate are partially solidified.

6. A process as claimed in any one of claims 1 to 3, in which the droplets when deposited on the substrate are in a solid state.

7. A process as claimed in any one of claims 1 to 6, in which the first fluid is inert.

8. A process as claimed in any one of claims 1 to 6, in which the first fluid is chemically reactive.

9. A process as claimed in any one of claims 1 to 8, in which the first fluid contains particulate matter.

10. A process as claimed in any one of claims 1 to 9, in which the second fluid is inert.

11. A process as claimed in any one of claims 1 to 9, in which the second fluid is chemically reactive.

12. A process as claimed in any one of claims 1 to 11, in which the second fluid contains particulate material.

13. A process as claimed in any one of claims 1 to 12, in which the molten metal is a single metal, an alloy or a mixture of metals.

14. A process as claimed in any one of claims 1 to 13, in which the molten metal is a liquid containing solid particles.

15. A process as claimed in any one of claims 9, 12 or 14, wherein the particles are reactive.

16. A process for producing a metallic article substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

17. A metallic article whenever produced by a process as claimed in any one of claims 1 to 16.

18. An apparatus for producing a metallic article, which comprises means for producing a Coanda Effect, means for providing a source of molten metal to be entrained in the Coanda Effect, and means for receiving metal droplets produced thereby to form a metallic article.

19. An apparatus as claimed in claim 18 enclosed in housing means to isolate and control the metallic article formation.

20. An apparatus as claimed in claim 18 or 19, in which the metal droplets are deposited on a substrate to produce a coated metal article.

21. An apparatus as claimed in claim 18 or 19 in which the metal droplets are deposited on a collector to produce a cast shape.

22. An apparatus as claimed in any one of claims 18 to 21, in which the receiving means is a linear moving holder.

23. An apparatus as claimed in any one of claims 18 to 22, in which the means for producing a Coanda Effect comprises a Coanda surface, means for flowing a first fluid along the Coanda surface and a second fluid located adjacent the Coanda surface to be influenced by the flow of the first fluid towards an intersection with the first fluid.

24. An apparatus as claimed in claim 23, including means for controlling the properties of the fluids.

25. An apparatus as claimed in claim 23 or 24, including a housing having one side thereof including the Coanda surface.

26. An apparatus as claimed in claim 25, in which the housing has a chamber defined therein and means for introducing the first fluid into the chamber and a fluid exit defined on the housing adjacent the Coanda surface.

27. An apparatus as claimed in any one of claims 23 to 26, in which the molten metal flow means is elongate to form a sheet of molten metal.

28. An apparatus as claimed in any one of claims 23 to 26, in which the molten metal flow means is a series of one or more orifices.

29. An apparatus as claimed in any one of claims 23 to 28, in which the Coanda surface is configured in a linear shape.

30. An apparatus as claimed in any one of claims 23 to 28, in which the Coanda surface is configured in a non-linear shape.

31. An apparatus as claimed in any one of claims 18 to 30, in which the receiving means includes a substrate or collector movable relative to the flow of metallic particles.

32. An apparatus as claimed in claim 31, in which the movement is transverse to the flow of metallic droplets.

33. An apparatus as claimed in claim 31, in which the receiving means includes a holder/collector which moves in the same direction but substantially away from the flow of metallic droplets.

34. An apparatus as claimed in any one of claims 18 to 30, in which means producing the Coanda Effect is movable relative to the receiving means.

35. An apparatus for producing metallic articles substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

36. A metallic article whenever produced using an apparatus as claimed in any one of claims 18 to 35.

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