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(54) Casting of metal strip.

(57) A method of casting metal wherein the molten metal is deposited on a moving planar substrate formed from an insulating refractory material. The deposited liquid metal is maintained as a liquid until the turbulence induced by the pouring of the metal onto the substrate is minimized. In order to increase cooling rate, the strip is preferably moved across a mesh substrate 50, 132, 186 where its lower surface is cooled. Ideally, this occurs as soon as the bottom of the strip has sufficient strength to support the remainder of the strip on the mesh.

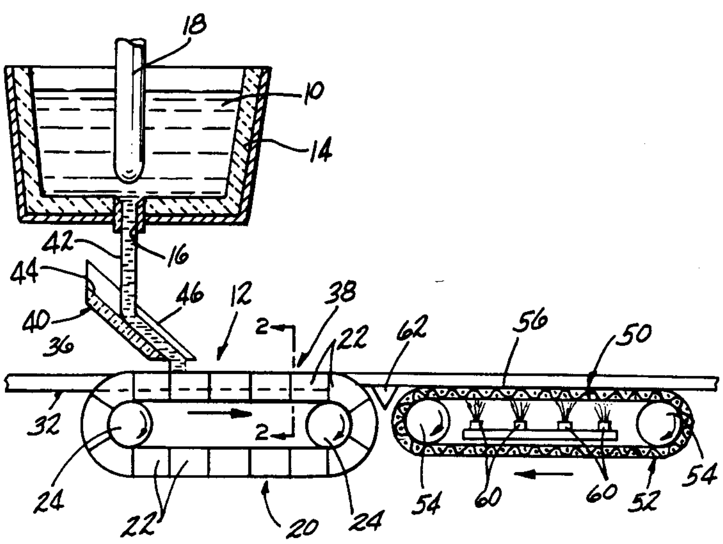

FIG-1

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This invention relates generally to the casting of metal, and more particularly, to an improved method and apparatus for the casting of metal strip or sheet in a continuous operation.

The metals industry has been developing processes and apparatus for producing an as-cast product that needs little or no additional processing such as hot rolling to reduce it to strip form. One such process that has arisen as a result of this development is the single belt casting process. In this process, molten metal is caused to flow onto a moving horizontal surface in the form of a continuous belt whereupon it solidifies as it moves along with the belt. The elongated solid strip of metal is removed from the continuous belt for further processing as desired.

As attempts have been made to increase the speed of casting as measured in inches per minute of the cast strip, as well as to reduce the thickness of the cast alloys to eliminate further processing operations, several problems have arisen in connection with the feeding of the molten metal onto the belt due to the splashing and turbulence caused by the relative flow between the melt and the belt.

Normally the source of molten metal is usually spaced at some vertical distance from the belt. When the molten metal is caused to flow directly from the source of the molten metal through the vertical distance into the belt, the melt will tend to splash as it hits the belt which may result in porosity in the cast product as well induce turbulence which can cause inclusions such as oxides and folds and creases in the outer surface of the solidified strip.

The typical approaches undertaken in an attempt to solve these problems involves improvements in the feeding means such as providing a tundish between the source of molten metal and the belt. Such feeding means normally takes the stream of molten metal issuing from the source and discharges it outwardly in the direction of movement of the belt. Although this approach solves the problem of splashing, the problem of dampening of its flow to reduce turbulence still remains.

Another disadvantage of belt casting processes is the low cooling rate of the molten metal on the belt. As the metal solidifies upon the belt, an air gap forms between the belt and the strip. These air gaps are poor thermal conductors and result in non-uniform heat transfer from the metal. This leads to poor product quality such as cracking and porosity in the metal.

The following references contain a discussion of various delivery systems used for the delivery of the melt to belt casters.

J. Herbertson, P. C Campbell, A. G. Hunt and J. Freeman, "Strip Casting Studies at BHP Central Research Laboratories", CCC'90 Fifth International Casting Conference, Voest Alpine, Industrieanlangenbau, Linz, June, 1990; J. Herbertson and R. I. L. Guthrie, "A Novel Concept for Metal Delivery to Thin Strip Casters", Casting of Near Net Shaped Products, TMS-AIME, pp. 335-349; and J. S. Truelove, T. A. Gray, P. C. Campbell and J. Herbertson, "Fluid Dynamics in High-Speed Strip-Casting Metal Delivery System", International Conference on New Smelting Reduction of Near Net Shape Casting Technologies for Steel, SRNC-9, J. S. Truelove, pp. 1/10-11/10.

While a great deal of attention has been directed toward the development of feed systems to reduce or minimize liquid metal turbulence and get better cooling rates so as to produce a high quality strip, the efforts in this direction have not been totally satisfactory.

Accordingly, it is an object of the present invention to provide an improved casting system for minimizing liquid metal turbulence.

It is also an object of the present invention to provide an improved casting system wherein molten metal is cast into strip in which the cooling rate of the casting is improved.

In accordance with the present invention, the turbulence is minimized by allowing the incoming liquid metal to damp itself by delaying solidification until the desired degree of damping occurs. This may be accomplished in accordance with the present invention by virtue of a process in which a moving substrate is passed beneath a source of molten metal with a planar portion thereof passes through a position at which a deposit of molten metal is placed on the substrate. The molten metal is maintained as a liquid on the moveable substrate until the turbulence is damped by itself and is thereafter cooled to induce solidification.

The cooling rate objects of the present invention may be achieved through a process which comprises providing a source of molten metal, passing a moving substrate underneath said source of molten metal having a planar portion thereof passing through a position at which a deposit of molten metal is placed on said substrate and forms a strip thereon. The strip is removed from the moving belt onto an open mesh support prior to the strip becoming completely solidified throughout its thickness upon which is supported until it fully solidifies.

An apparatus for practicing the present invention includes a source of molten metal, a moving substrate having a planar portion mounted for movement through a position at which a deposit of molten metal is placed on said substrate and forms a strip thereon, and an open mesh support upon which the strip is passed prior to becoming completely solidified on said moving substrate.

The present invention may be more readily understood by reference to the following detailed description and to the accompanying drawings in which:

Figure 1 is a schematic elevational view, partially in section, of a casting apparatus incorporating the present invention;

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

Figure 3 is a schematic elevational view, partially in section, of one embodiment of a casting apparatus incorporating the present invention; and

Figure 4 is a schematic elevational view, partially in section, of a second embodiment of a casting apparatus incorporating the present invention.

The present invention is directed to the casting of strip or sheet from molten metal. By strip or sheet is meant metal having a rectangular cross-section of greater width than thickness and in which the thickness is between about 1/8 to about 3/4 inch and preferably between about 1/4 to about 1/2 inch. While the invention may be applicable to many metals, it is particularly applicable to the casting of copper or copper alloys.

Referring to the drawings, and in particular to Figure 1, there is shown schematically a casting system which incorporates the present invention. The molten metal 10 may be supplied to the casting apparatus 12 from a refractory lined vessel 14 having a discharge opening 16 therein. A plunger 18 is provided in the interior of the vessel 14 which is associated with the discharge opening 16 to control the flow of molten metal from the vessel 14. For this purpose, the plunger 18 may be vertically reciprocated by any suitable mechanism (not shown).

A continuously moving substrate arrangement 20 is mounted beneath the discharge opening 16 of the vessel 14. The substrate arrangement 20 may include a continuous belt or caterpillar of a plurality of interconnected segments or blocks 22 extending between horizontally spaced rollers 24. One of the rollers 24 may be connected to a suitable drive means (not shown) to drive the segmented belt 24 at the proper speed and in the direction indicated by the arrow. These segments or refractory blocks 22 are fabricated from a suitable refractory material which acts as an insulator against the transfer of heat from the molten metal cast upon it.

As shown in Figure 2, the blocks have a trough portion 26 formed therein extending inwardly from the outer surface thereof. The trough 26 is formed by a flat bottom surface 28 and opposed sidewalls 30. The trough portions 26 form a continuous trough in the substrate arrangement 20 which extends in the direction of the movement thereof.

A preformed foil material 32 having a bottom surface 34 and sidewalls 36 is fed onto the upper run 38 of the substrate assembly 20 and is adapted to move along with the blocks 22. The foil is so shaped such that it fits within the trough portions 26 in the blocks 22. The foil material may be made from low carbon steel though any steel alloy ranging from low carbon to stainless steel may be used. The foil must be of sufficient thickness such that the molten metal will not dissolve through it prior to the molten metal being cooled. The foil preferably should have a thickness of 0.01 inch or less and may generally be between 0.002 and 0.01 inch. The foil may be shaped into its trough-like cross-section by any suitable means (not shown) such as shaping bars or rollers. The foil 32 is fed from a suitable supply to the upper run 38 of the substrate assembly 20 and is moveable therewith.

Feeding means such as a refractory lined tundish 40 is provided between the vessel 14 and the continuous substrate arrangement 20 in a position to be contacted by the stream 42 of the molten metal issuing from the outlet 16 of the vessel 14. The tundish 40 may include a refractory lined trough-like member having a generally flat inclined bottom surface 44 with vertically extending side edges 46. The tundish 40 is inclined as shown in Figure 1 such that its flat planar bottom surface 44 is inclined downwardly toward the downstream end of the upper run 38 of the continuous substrate 20.

A supporting surface 50 is provided downstream of the upper run of the moving substrate 20. This supporting surface 50 is of a filter-type material such as expanded mesh through which air and water can pass. The supporting surface 50 may be in the form of a continuous belt 52 mounted on rollers 54 and providing a planar upper run 54 coplanar with the bottom of the troughs 26. The continuous belt 52 moves in the direction as indicated by the arrow in Figure 1. Alternatively, the supporting surface 50 may be in the form of a table and pinch rollers may be provided downstream thereof to grip the foil and cast strip and pull it across the table. The expanded mesh may be fabricated from steel although such other materials as copper, copper alloys and aluminum may be used.

Cooling sprays 60 are provided underneath the upper run 52 of the supporting mesh material 50 to cool the bottom surface of the foil and strip contained thereon.

A static support surface 62 may be provided which is coplanar with the bottom of the trough of the upper run 38 of the substrate assembly 20 and the upper run 56 of the supporting surface 50 to close the gap therebetween.

In operation, the molten metal is caused to flow from the tundish 40 into the troughs 26 in the refractory blocks forming the upper run of the continuous belt which is lined with the preshaped foil 32. The length of the upper run 38 of the moving substrate 20 in which the metal is in contact should be long enough to ensure that the molten metal contained therein remains liquid until the turbulence is damped by itself and the molten metal becomes a static fluid in contained by the foil in the troughs and has reached a quiescent state with respect to the foil. During this process, no cooling of the refractory blocks 22 or molten metal is provided. The preformed foil 32 may be inductively preheated to minimize distortion upon being contacted by the molten metal feed. While the contact length of the upper run of the moving belt will vary depending upon the alloy being cast, in the case of copper alloys it is thought that the upper run need be no longer than about 6 to about 10 inches and probably about 8 inches.

After the molten metal has become quiescent, the metal and foil passes onto the supporting planar surface 50 where the cooling is applied by the cooling sprays 60. The cooling sprays 60 spray water or other cooling fluids upwardly through the mesh material of the planar surface 50 against the bottom side of the foil. After completely solidifying, the cast metal and the foil are removed from the supporting surface 50, it may be further processed as desired.

The foil, if it becomes welded to the cast metal strip, may be removed by conventional milling. The foil may also be coated with an appropriate material such as boron nitride or graphite before the molten metal is deposited thereon so as to permit the foil to be separated from the solidified strip and reused.

By virtue of the above-described arrangement, the turbulence of the liquid being cast upon a horizontal moving belt is minimized by maintaining the cast metal on the moving belt as a liquid until the turbulence dissipates itself at which time the cast molten metal is cooled to provide a solidified strip.

Referring now to the drawings in detail, and in particular Figures 3 and 4, there is shown schematically one embodiment of a casting system which may be used to practice the present invention. The system includes a moving substrate 110 in the form of a casting wheel or drum 112 having a cylindrical outer surface 114. A groove 116 extends about the outer surface 114 and is defined by a base and opposed side edges. The wheel or drum 112 is rotatable about its axis in the direction indicated by the arrow in Figure 3 by means of a suitable mechanism (not shown) such as a motor.

A tundish 122 is supported in close proximity to the casting wheel or drum 112 and contains a supply of molten metal 124. The tundish 122 has an outlet or nozzle 126 at which a meniscus 128 of molten metal 124 is formed which is maintained in contact with the outer surface 114 of the wheel or drum 112. The tundish 122 is supported in fixed relationship to the wheel or drum 112 by a suitable frame structure (not shown).

As the wheel or drum 112 is rotated, the outer surface 114 thereof passes by the nozzle or outlet 126 of the tundish 122, and contacts the meniscus 128 the molten metal 124. The molten metal 124 substantially wets the outer surface of the drum or wheel 112 and is dragged along with it forming a deposit thereon positioned within the groove 116. The metal continues moving with the drum or wheel 112 until it is withdrawn tangentially therefrom as a strip 130 at the vertical apex.

The tundish 122 may be constructed from a high strength, thermally-insulating material such as a cast ceramic material or a rigid metal frame structure lined with suitable refractory material to minimize heat loss from the molten metal 124 contained within the tundish 122 during operation.

The wheel or drum 112 may be formed of any suitable material such as metal which will not melt or fracture under the operating conditions. Suitable metals include steel or copper or copper alloys. Other materials which may be used include graphite and ceramic material such as boron nitride.

A mesh supporting surface 132 for the strip 130 is provided downstream of the drum or wheel 112 as shown. This supporting surface 132 is of a filter-type material such as expanded mesh through which air and water can pass. Ideally, this supporting surface 132 is in the form of a moveable continuous belt 134 mounted on spaced rollers 136 which moves in the direction as indicated by the arrows in Figure 3 and which provides an upper run 138. Alternatively, the surface 132 may be in the form of a static table and the strip 130 moved across the table by driven pinch rollers positioned downstream of the upper surface 150. The expanded mesh may be fabricated from steel, preferably stainless steel.

The upper run 138 is positioned in a plane tangential with the vertical apex of the drum or wheel 112. A static support 140, coplanar with the upper surface of the upper run 138 may be provided between the wheel or drum 112 and the upstream end of the upper run 138 of the belt 134 to close any gap therebetween. Cooling sprays 142 are provided underneath the upper run 138 of the supporting mesh material 132 to spray cooling fluid such as water through the mesh belt 134 against the bottom surface of the strip 130.

In operation, the molten metal flowing from the outlet 126 of the tundish 122 forms a meniscus 128 against the rotating wheel or drum 112. Molten metal from the meniscus 128 is dragged along with the rotating drum and is positioned within the groove 116. The length of travel of metal on the drum before the strip 130 is removed therefrom at the vertical crest and is set so that the strip 130 of the cast metal will pass onto the mesh surface 132 prior to the strip 130 becoming completely solidified throughout its cross-section. Ideally, the strip 130 is caused to pass onto the open mesh 132 as soon as a solidified shell forms on the bottom surface and side surfaces of strip 130 which is thick enough so as not to fracture under the weight of the remaining molten metal.

Referring to Figure 4, a second embodiment is shown schematically of a casting system which incorporates the present invention. Molten metal 150 may be supplied to the casting apparatus 152 from a refractory lined vessel 154 having a discharge opening 156 therein. A plunger 158 is provided in the interior of the vessel 154 which is associated with the discharge opening 156 to control the flow of molten metal from the vessel 154. For this purpose, the plunger 158 may be vertically reciprocated by any suitable mechanism (not shown).

A continuous moving belt arrangement 160 having an upper planar horizontal run 162 is mounted beneath the discharge opening 156 of the vessel 154. The belt arrangement 160 includes a flexible belt 164 entrained about and extending between horizontally spaced rollers 166. One of the rollers 166 may be connected to a suitable drive means (not shown) to drive the belt 164 at the proper speed in the direction indicated by the arrow.

The belt 164 may be made of a solid material such as steel, and preferably a low carbon steel, although other materials may be used so long as the material will not melt through when contacted by the molten metal being cast.

Feeding means such as a refractory lined tundish 170 may be provided between the vessel 154 and the continuous belt arrangement 160 in a position to be contacted by the stream 166 of the molten metal issuing from the outlet 156 of the vessel 154. The tundish 170 may include a refractory lined trough-like member having a generally flat inclined bottom surface 172 with spaced vertically extending side edges 174. The tundish 170 is inclined as shown in Figure 3 such that its planar bottom surface 172 is inclined downwardly toward the downstream end of the upper run 162 of the continuous belt 164. Spaced side dams 176 may be provided which may be either moveable with the belt or a static structure along each edge of the upper run 152 of the belt 154 to contain the molten metal in a transverse direction to the movement of the belt 154.

A supporting surface 180 is provided downstream of the upper run 162 of the moving belt 160. This supporting surface 180 is similar to the supporting surface 132 of the previous embodiment shown in Figure 3 and is of a filter-type material such as expanded mesh through which air and water can pass. This supporting surface 180 may also be in the form of a continuous belt 182 mounted on spaced rollers 184 and which provides an upper run 186 moving in the direction as indicated by the arrows in Figure 3. As in the case of the previous embodiment, the surface 180 may alternatively be in the form of a static table and the strip moved across the table by driven pinch rollers positioned downstream of the upper surface 150. The expanded mesh may be fabricated from steel, and preferably stainless steel.

The upper run 186 is coplanar with the upper run 162 of the belt 164. A static support surface 188 coplanar with the upper surfaces of the upper runs 162 and 186 may be provided between the downstream end of the upper run 162 of belt 164 and the upstream end of the upper run 186 of the belt 182 to close the gap therebetween.

Cooling sprays 190 and 192 are provided underneath the upper run 162 of the moving belt 164 and underneath the upper run 186 of the supporting mesh material 186 respectively to cool the bottom surface of the strip.

In the operation of this embodiment, the molten metal 166 is caused to flow from the tundish 170 onto the upper run 162 of the moving belt 166. The length of this upper run 162 upon which the metal is in contact therewith (contact length) is set so that the strip 100 of the cast metal will pass onto the mesh support 180 prior to the strip 100 becoming completely solidified throughout its cross-section. Ideally, the strip 100 is caused to pass onto the open mesh support 180 as soon as a solidified shell forms on the bottom surface thereof which is thick enough so as not to fracture under the weight of the remaining molten metal. While the contact length of the upper run of the moving belt will vary depending upon the effective cooling provided as well as the alloy being cast, in the case of copper alloys with bottom cooling, the upper run should be in the range of about 4 to 8 inches and preferably about 6 inches.

By virtue of the above-described arrangement, the cooling rate of the casting is improved by virtue of the fact that the air gap which normally forms between a solid substrate and a strip is eliminated.

While the invention has been described above with reference to specific embodiments thereof, it is apparent that many changes, modifications and variations can be made without departing from the inventive concept disclosed herein. Accordingly, it is intended to embrace all such changes, modifications and variations that fall within the spirit and broad scope of the appended claims.

Claims

1. A process for casting metal 10 into sheet 36 or strip characterized by:
   (a) providing a source 14, 16 of molten metal,
   (b) passing a moving substrate 20 underneath the source of molten metal with a planar portion 26 thereof passing through a position at which a deposit of molten metal is placed on said substrate,
   (c) feeding said molten metal onto said substrate, and
   (d) maintaining said molten metal on said substrate as a liquid until turbulence is dissipated and thereafter and cooling the metal to form a solidified strip.

2. The process of claim 1 characterized in that said moving substrate 20 comprises a refractory material.

3. The process of claim 1 or 2 further characterized by providing a foil material 32 on said substrate 20 between the source 14, 16 of molten metal and said substrate to receive the molten metal.

4. The process of claim 3 further characterized in that said substrate has a trough 34, 36 therein and said foil is fed onto and moves with said substrate and lines said trough, said foil and molten metal remaining on said substrate until said molten metal becomes quiescent with respect to said foil and thereafter removing said foil and metal from said substrate 20 onto a support surface 50 and cooling said molten metal.

5. The process of claim 4 further characterized in that said supporting surface 50 is mesh and said cooling of said metal includes water sprays 60 directed against the bottom of said foil through said mesh.

6. A process for casting metal characterized by:
   (a) providing a source 14 of molten metal,
   (b) passing a moving substrate 110 through a position relative to said source of metal to receive a deposit of molten metal thereon which forms into a strip 130 thereon, and
   (c) removing said strip 130 from said moving substrate onto an open mesh support 132 prior to said strip becoming completely solidified throughout its thickness, said open mesh support supporting said strip as it fully solidifies.

7. The process of claim 6 further characterized by applying cooling 142 to the underside of the strip positioned against said mesh.

8. The process of claim 6 or 7 further characterized in that said strip 130 is removed from said moving substrate immediately after it forms a solidified shell on its underside thick enough not to fracture under the weight of the remaining molten metal.

9. The process of any one of claims 6 to 8 further characterized in that said moving substrate is a rotating wheel 110.

10. The process of any one of claims 6 to 8 further characterized in that said moving substrate is an endless belt 160.

11. The process of any one of claims 6 to 10 further characterized in that said open mesh support is a continuous belt 132, 180.

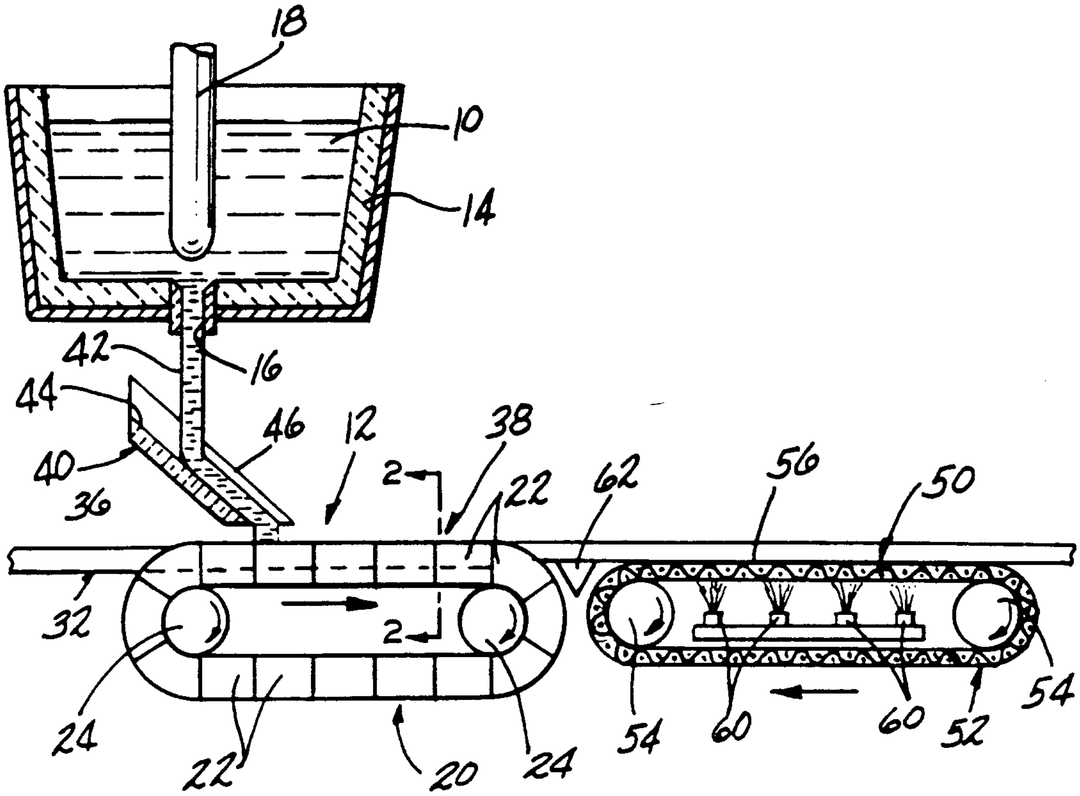
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FIG-1

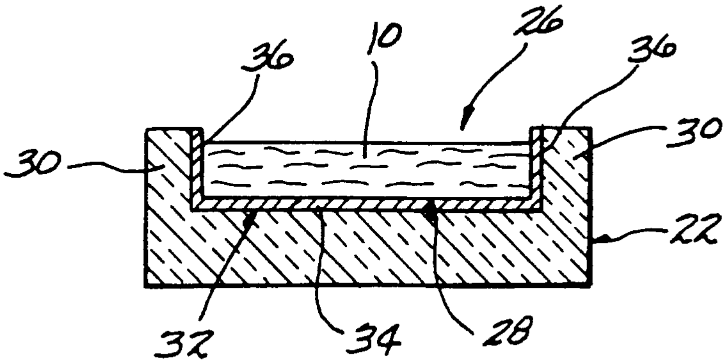
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FIG-2

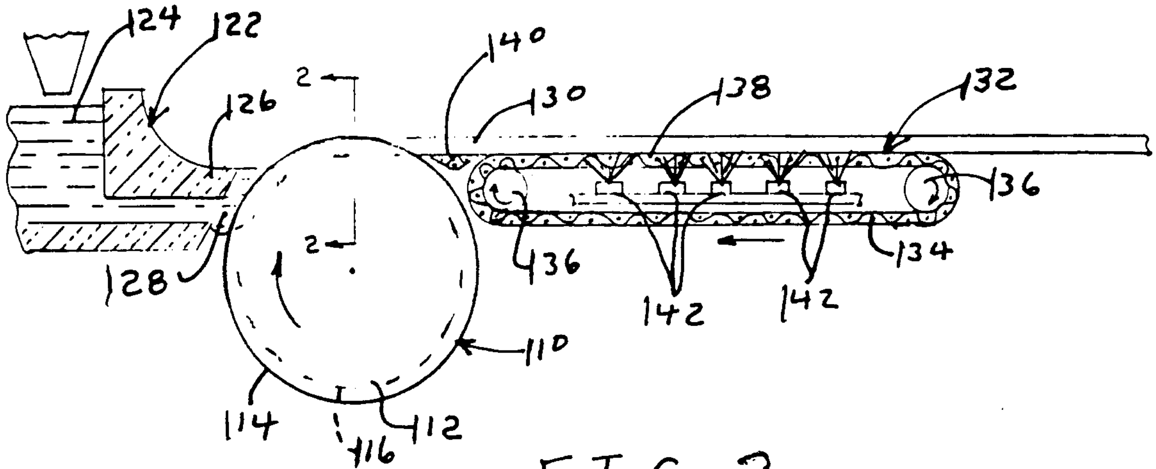
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FIG. 3

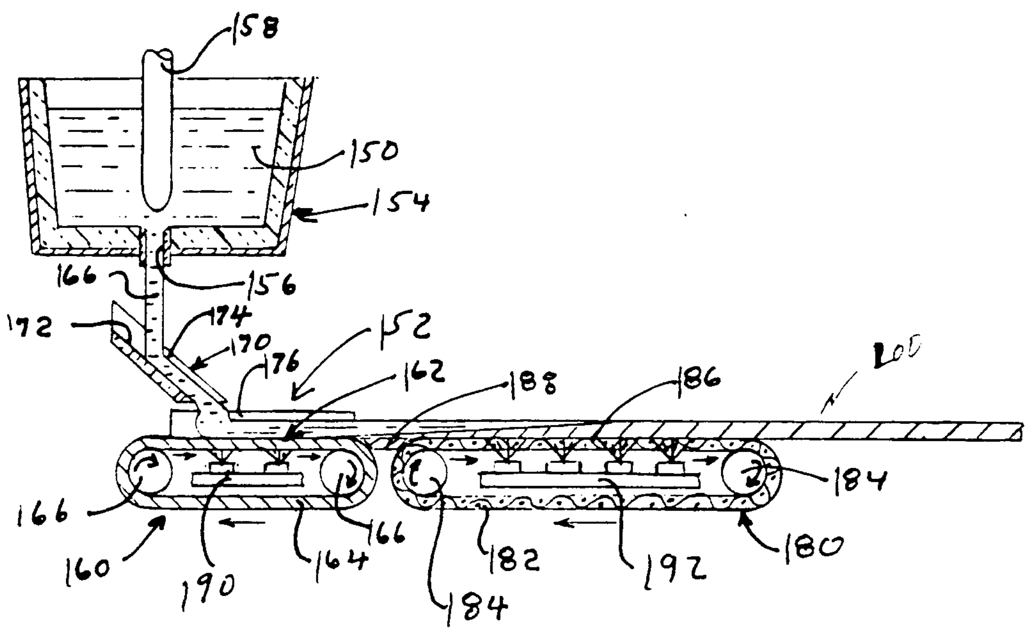
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FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 11 3351

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X A	GB-A-1 551 755 (BRITISH STEEL CORPORATION) * page 1, line 98 - page 3, line 10; figures 1,2 * ---	1-4 10	B22D11/06
X	US-A-3 343 590 (F.J.RADD) * column 2, line 22 - column 3, line 68; figures 1-4 * ---	1,3,4	
A	GB-A-2 010 146 (BRITISH STEEL CORPORATION) * page 1, line 62 - page 2, line 29; figures 1,2 * ---	1	
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 33 (M-452)(2090) 8 February 1986 & JP-A-60 187 448 (KOBE SEIKOSHO KK) 24 September 1985 * abstract * ---	1	
A	GB-A-2 183 185 (OCC COMPANY LTD) * abstract; figure 1 * -----	1	TECHNICAL FIELDS SEARCHED (Int. Cl.5) B22D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25 NOVEMBER 1992	MAILLIARD A.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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