

DIRECT CASTING OF METALLIC WIRE PRODUCTS

This invention relates to a method and apparatus for manufacturing metallic wire products by direct casting. In conventional metal wire manufacturing methods, where
5 the term wire is understood to refer to a product having relatively small cross-sectional area and substantial length, a bath of the metal is cast batchwise to ingots or continuously to strands, which are divided transversely to their longitudinal direction into wire billets. The
10 ingots and billets have a cross-sectional area of about $10,000 \text{ mm}^2$ or more and are hot rolled in rolling mills to suitable cross-sections, which for steel normally are round with a diameter of 5 to 9 mm. The wire thus produced is subjected to further treatment by being drawn
15 in the cold state.

The manufacturing method schematically described above is very expensive and involves material losses. The rolling mill and other equipment are extensive, because the difference between the cross-sectional area of the
20 starting material, i.e. ingots or billets, and the cross-sectional area of the hot-rolled wire is great and requires a great number of passes. The material, besides, must have good machinability, which primarily depends on the analysis of the material and, therefore, implies
25 restrictions from a material point of view.

A satisfactorily operating method of direct wire casting where a relatively small cross-section is cast substantially continuously, therefore, must offer a great

-2-

number of obvious technical and economic advantages. At present no method exists by which the considerable technical problems involved in such a direct casting process have been solved, and, therefore, no method is
5 applied in commercial production, either.

One known tested method of direct casting is the Michelin process, in which a jet of molten metal is pressed out at high pressure through a small aperture nozzle, whereby under favourable conditions a wire of
10 about 0,2 mm diameter can be formed.

By maintaining a high silicon content in the bath and by surrounding the jet with an oxygen gas atmosphere, according to Michelin an oxide shell is formed which holds the jet together until it has solidified. The method,
15 which so far has been tested only on a laboratory scale, is very difficult to control. It, further, permits production of only very thin wire and requires high silicon contents in the wire material.

Other direct casting methods have been tested, in
20 which primarily a rapidly solidifying structure of the wire is desired. In these cases very small dimensions are endeavoured, and promising results have been obtained on a laboratory scale with alloys having a low liquidus temperature, i.e. temperature of commencing solidification.
25 Due to the small dimensions, however, these methods are without interest from a production aspect for "normal" products and material types. Methods for the manufacture of steel fibres from a molten bath are known and have been

-3-

developed close to commercial production. In these methods a wheel is rotated so that a portion of its periphery is immersed in the bath. It was, however, found unfeasible to manufacture in this way a coherent wire with acceptable cross-section. A further method known is "dip forming", which is used for applying a very pure outer coat of copper on copper wire. It was found possible by this method to "freeze on" a coat on a wire by dipping the wire into a molten bath of the same material as the wire.

10 For technical reasons, however, this method is not adapted for use on steel. The method rather is to be regarded as a method of surface coating.

Conclusively one may say, that in spite of the obvious technical and economic advantages implied in the direct casting of steel wire products, no working method is yet available.

In principle, the simplest method of manufacturing wire by direct casting should be to cause the molten metal to flow out through an opening, a so-called nozzle, of a container and thereby to form a coherent jet intended to solidify to a wire. It involves, however, problems unsolved so far how to cause such a jet to solidify to wire of desired dimensions. Due to the high surface tension of the steel, a strong tendency of breaking-up the jet into droplets arises, because from an energetic aspect the form of droplets is more favourable for the bath.

25 This tendency further is favoured by requirements on decreasing diameters, owing to the accelerating effect of

-4-

gravity on the jet in combination with requirements on constant volume.

The present invention relates to a simple solution of the aforesaid problems in connection with the outflow of molten metal, where a wire continuously runs out through said opening or nozzle. The wire tends to be enclosed by the metal in the jet and stabilizes the jet for so long a period as required by the molten metal to solidify, whereby a continuous wire is obtained, the diameter of which exceeds the diameter of the wire running-out, supplied. The process can be controlled, e.g. by adjusting the height of the molten metal, i.e. the bath depth, the running-out rate of the wire and the temperature of the bath.

In one aspect the present invention provides a method of manufacturing metallic wire products by direct casting of molten metal, the method comprising:

A) providing a bath of molten metal in a container having an outlet hole in the bottom thereof through which the metal can flow;

B) passing a wire out through the outlet hole in the bottom of the container, the wire being of a metal having a melting point close to that of the molten metal, and having a diameter substantially smaller than that of the outlet;

C) flowing freely a jet of said molten metal out of said outlet hole, thereby forming an unbroken wire shaped body of said jet that is stabilized by said wire; the rate

-5-

at which the wire passes out through the outlet hole being substantially the same as or greater than the rate at which said jet flows out of the outlet hole;

D) cooling the unbroken jet of molten metal surrounding the wire and causing it to solidify around the wire; and

E) collecting the wire and solidified surrounding molten metal.

In a second aspect the invention provides an apparatus for manufacturing metallic wire products by direct casting of molten metal, said apparatus comprising: a bath of said molten metal in a container including a bottom in which is formed an outlet hole; wire supply means at least partially located above the container, for supplying wire through said bath and outlet hole, the supply means including wire having a melting point close to that of the molten metal, and a diameter substantially smaller than that of the outlet hole, so that the molten metal of said bath can flow freely as a jet through said outlet hole around said wire; cooling means for cooling said molten metal flowing out of said outlet hole to solidify a coating on said wire; and wire take-up reel means for coiling the wire with said solidified coat.

Some embodiments of the invention will now be described in greater detail with reference to the accompanying drawings, in which:

-5a-

Fig. 1 is a vertical section through a schematically shown first embodiment of an apparatus for carrying out the invention,

Fig. 2 is a vertical section through an outlet hole
5 (nozzle) of the apparatus according to Fig. 1, shown in greater detail,

Fig. 3 is a vertical section through a schematically shown portion of a second embodiment of an apparatus for carrying out the method according to the invention,

10 Fig. 4 is a vertical section through a schematically shown portion of a third embodiment of an apparatus for carrying out the method according to the invention, and

Fig. 5 is a vertical section through a schematically

-6-

shown portion of a fourth embodiment of an apparatus for carrying out the method according to the invention.

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In Fig. 1 the numeral 1 designates an uncoiling reel or the like, from which a metal wire 2 is to run off. The uncoiling reel 1 may be a wire magazine, but may also be a block, to which wire from a magazine is taken and intended
10 to run off from the block.

Preferably beneath or on the same level as the uncoiling reel 1 a container 3, a so-called casting box 3 or the like, is located which is intended to hold a bath 4 of molten metal to be applied on the wire 2. In the
15 bottom 5 of the container 3 an outlet hole 6 for molten metal is located, for example in a so-called nozzle 7 or the like, which nozzle consists, for example, of a perforated ceramic insert 7 in the bottom 5 of the container 3.

20 The wire 2 is intended to be introduced into the bath 4, to be passed therethrough and out of the bath 4 and container 3 through the outlet hole 6, which has a diameter exceeding substantially the diameter of the wire 2. Thus, molten metal is intended to flow out of the bath 4 through
25 the outlet hole 6 along the wire 2 and to form a coat 8 about the wire 2.

Preferably beneath the container 3 a cooling device is

-7-

provided which substantially comprises a container 9 or the like with a coolant 10, such as a liquid or melt. Through said coolant 10 the wire 2 with the coat 8 of molten metal flown-out is intended to be passed. In many cases a coolant is preferred which at the contact with the coat does not vaporize.

The container 9 is arranged in a way suitable for the purpose, for example upwardly open and having a hole 11 in its bottom 12 where preferably a sealing 13 of a suitable kind is located in connection to the hole 11 for sealing against the wire 2 with the coat 8, as appears from Fig. 1.

The cooling device 9,10 preferably is designed for circulation of coolant 10 by means of a collecting container 14 and a return conduit 16 provided with a pump 15, as schematically indicated in Fig. 1.

The wire 2 with said coat 8, after having passed through the cooling device 9,10, is coiled on a coiling reel 17. At this time the coat 8 is supposed to have solidified.

In Fig. 2 the outlet hole 6, nozzle 7 and wire 2 with coat 8 are shown in greater detail.

In Fig. 3, which refers to a second embodiment of an apparatus according to the invention and where the cooling device 9,10 is not shown, the numeral 18 designates a pipe or the like of, for example, ceramic material, which pipe 18 is immersed into said bath 4 of molten metal. The pipe 18 is located so that its upper mouth 19 preferably is located above the upper surface 20 of the bath 4, and its

-8-

lower mouth 21 is located in connection to the outlet hole 6 in the bottom 5 of the container 3. Through said pipe 18 the wire 2 is intended to be introduced into the bath 4. The pipe 18 preferably can be lifted and lowered, and its lower mouth 21 preferably is designed and intended for sealing against the container 3 on the inside 22 thereof at said outflow hole 6, so that the outflow of molten metal from the bath 4 through the outlet hole 6 can be adjusted and/or shut off completely by means of said pipe 18.

The pipe 18 can be disposed and designed as shown in Fig. 4 where a coolant 23, such as liquid argon, is to be introduced into the pipe 18 and intended to cool the wire 2 at its passage through the pipe 18. The pipe 18 here is formed, for example, with an opening 24 close to its upper mouth 19, through which opening the coolant 23 can be supplied under pressure via a feed conduit 25. It is, of course, possible to provide several openings 24 and feed conduits 25. The numeral 26 designates a sealing between the wire and the pipe 18 at the upper mouth 19 of the pipe where the wire 2 is intended to be introduced.

The pipe may be designed as shown in Fig. 5 where radially directed holes 27 are located slightly above the lower mouth of the pipe, through which holes molten metal from the bath 4 is intended to be supplied to the pipe and wire.

In connection to said outlet hole 6, irrespective of its specific design, means of known kind can be provided for the generation of magnetohydrodynamic (MHD) force fields, for example as shown in Fig. 2, which means are
5 designated by 31. The MHD means are arranged so that the molten metal flowing out through the outlet hole 6 can be braked, and that generated braking force can be varied. The MHD means further contribute to quiet solidification and a uniform surface of the solidified coat.

10 The apparatus embodying the invention operates as follows.

The wire 2 for stabilising the cast metal is passed from the uncoiling reel 1 down into the bath 4 of molten metal in the container 3, which metal is intended to be
15 applied on the wire 2. The wire 2 thereafter is passed out of the bath 4 through the outlet hole 6 in the bottom 5 of the container 3. The outlet hole 6 has a diameter which substantially exceeds the diameter of the wire 2. Molten metal flows out through the outlet hole and along
20 the wire, which acts coherently on the jet and prevents the jet from _____

-10-

being broken-up into droplets.

The said jet constituting a coat of molten metal, thus, is applied on the wire where said coat will have a thickness depending e.g. on the diameter of the outlet hole in relation to the diameter of the wire.

The method includes the solidification of said molten metal coat, and, therefore, the temperature of the molten metal must be lowered, preferably by forced cooling, at first below the temperature to start solidification, the so-called liquidus temperature, and then below the temperature for complete solidification, the so-called solidus temperature.

The cooling is effected in several ways. The molten metal coat is cooled partly "from inside" the wire, provided that the wire has a lower temperature than the coat, and partly by surrounding medium, for example air, after the outflow out of the outlet hole. The main cooling, however, takes place forcedly when the wire is passed through the container 9 with coolant 10, where the coolant is a liquid, for example water or melt. The wire with applied solidified coat passes out through a hole provided with sealing in the container bottom, whereafter the wire with the coat is coiled by means of the coiling reel 17. Coolant possibly leaking is collected and returned to the container 9 when deemed suitable and possible. The necessary cooling effect of the cooling device varies with the volume to be cooled per time unit, i.e. with the coat thickness and rate of the wire. The

-11-

cooling effect can be adjusted according to demand e.g. by varying the bath depth in the container, where said effect increases with the bath depth. It can also be imagined to pass the wire in some form of loop through the container
5 whereby the staying time in the bath and thereby the cooling effect increases.

The cooling, of course, also can be carried out in several other ways. Liquid or gas, for example, may be sprayed against the wire. Also contact cooling can be
10 imagined where the wire with the coat is passed between cooled rolls or the like. It is, of course, possible to combine several cooling methods.

Generally applies that the cooling must be adjusted so that the coat of molten metal has solidified substantially
15 completely prior to the coiling. At a definite cooling effect, this implies restrictions with respect to coat thickness and wire rate.

Certain conditions or restrictions also are involved with the passage of the wire through the bath 4 of molten
20 metal prior to the application of said coat of molten metal. The wire, for example, of course must not be caused to melt on passage through the bath. When the material in the molten metal is the same as in the wire, the exposure time of the wire in the bath must be so short
25 that the temperature of the wire cannot increase to the solidus temperature for the material. The exposure time can be reduced by increasing the wire rate, but then the cooling must be taken into consideration, because as

mentioned before the requirements of cooling are higher the higher the wire rate is. The exposure time also may be reduced by shortening the distance through which the wire is passed through the bath. This preferably is

5 brought about by introducing the wire into the bath beneath its surface and close to the outlet hole. This is the function of the pipe 18 at the embodiment shown in Fig. 3 where the lower mouth of the pipe is intended to be held close to the outlet hole, and the inner diameter of

10 the pipe only insignificantly exceeds the diameter of the wire, so that molten metal does not rise in the pipe due to the small space between the wire and the inner wall of the pipe and due to the movement of the wire. This is also the main function of the pipe 18 at the embodiment

15 shown in Fig. 4. According to this embodiment the wire is also cooled by the coolant 23, which for example consists of liquid argon. The coolant 23 is introduced into the pipe under pressure and prevents molten metal from rising in the pipe. The cooling of the wire reduces the risk of

20 melting. This is also the main function of the embodiment according to Fig. 5 where the pipe slightly above its lower mouth is provided with the radially directed holes, through which molten metal from the bath is supplied to the pipe and wire. In a corresponding manner as at the

25 embodiment shown in Fig. 4, the coolant is introduced into the pipe whereby molten metal is prevented from arising in the pipe at the same time as the wire is cooled.

As indicated above, there exist, thus, a great number of possible combinations of conditions, under which said coat of molten metal can be applied and caused to solidify on the wire. Important parameters include the temperature of the wire, the liquidus and solidus temperatures of the wire, the temperature of the molten metal in the bath, the liquidus and solidus temperatures of the molten metal, the thermal diffusivity of the molten metal, the diameter of the outlet hole in relation to the wire diameter, the temperature of possible coolant and the heat transfer coefficient with respect to heat transfer between the coat and the coolant. Of great importance, of course, is also the rate at which the wire is passed through the bath and outlet hole, and the exposure time of the wire in the bath. Here also the height or depth of the bath has some effect under certain conditions.

Of great importance for the function of the process, of course, is the diameter or corresponding of the outlet hole in relation to the diameter or corresponding dimension of the wire. The thickness of the coat of

molten metal being applied, namely, corresponds substantially to the difference between the radius of the outlet hole and the wire radius. Under definite conditions in general, there exists, of course, a limit for the thickness of the coat to be applied.

In the Table below examples of condition combinations are shown, under which the method can be carried out. It is characteristic of said combinations, that the temperature of the molten metal is held only slightly higher than the liquidus temperature of the molten metal, which facilitates the solidification, and that the wire rate and the thickness of the coat applied have been adjusted so that reasonable requirements are raised on cooling after they have left the bath.

In the Table the terms as follows apply.

ϕ_t = wire diameter (mm)

ϕ_u = outlet hole diameter (mm)

v = wire rate (m/s)

T_s = temperature of molten metal in the bath (°C)

T_l = liquidus temperature of the molten metal (°C)

Wire material	Molten metal material	ϕ_t (mm)	ϕ_u (mm)	v (m/s)	T_s (°C)	T_l (°C)
1. Carbon steel SIS 2114	Carbon steel SIS 2114	0,5	1,0	10	1535	1515
25 2. Carbon steel SIS 2114	Stainless steel SIS 2343	1,0	2,0	5	1450	1420
3. Stainless steel SIS 2562	Stainless steel SIS 2562	0,2	0,4	30	1450	1405

The rate of the wire 2 can be higher than the rate of the molten metal 8 through the outlet hole 6, whereby a thinner product is obtained than if the rate of the wire 2 would correspond to the rate of the molten metal.

5 The diameter of the outlet hole preferably is 1,5 to 2 times greater than the wire diameter. The proportions, however, can be varied within wide limits by varying the remaining parameters (so long as the hole diameter is much the larger).

As will have become apparent from the aforesaid, the
10 method according to the invention offers a solution of the problems involved with the direct casting of wire. The method provides excellent possibilities of controlling the casting process where the process conditions can be varied within wide limits.

15 It is apparent that several variants of the method and embodiments of the apparatus according to the invention can be imagined without abandoning the invention idea.

The material in the wire, for example, can be
20 selected so that it has a solidus temperature, which is close to (e.g. slightly greater than) the temperature of the molten metal, whereby the risk of wire melting is eliminated or reduced.

The object of different materials in the wire and in
25 the bath also may be to give the outer coat of the completed wire better properties, for example with respect to corrosion resistance, than of the wire interior. This is a way of reducing material costs. A stainless steel,

for example, can be applied to a wire of unalloyed or low alloyed steel.

Substantially different properties of the wire 2 and the cast coat also can be obtained by adjusting the coat thickness and cooling so that the solidification proceeds extremely rapidly. Hereby an amorphous or substantially amorphous structure can be obtained which has extremely good strength properties.

In order to control the outflow of molten metal through the outlet hole, the molten metal bath, can be subjected to pressure, whereby the outflow can be controlled by controlling the pressure.

The uncoiling reel can be placed on the same level as or below the container for the bath, in such a manner that the wire is passed down into the bath via pulleys or the like. This is a way of holding short the total extension in vertical direction of the apparatus. In a corresponding way the wire, via pulleys or the like, can be passed out horizontally to the coiling reel, where at least a part of the cooling device may consist of a bath or the like in a horizontal groove or the like.

The invention, thus, must not be regarded restricted to the above embodiments of the method and apparatus, but can be varied.



-17-

CLAIMS:

1. A method of manufacturing metallic wire products by direct casting of molten metal, the method comprising:

A) providing a bath of molten metal in a container
5 having an outlet hole in the bottom thereof through which the metal can flow;

B) passing a wire out through the outlet hole in the bottom of the container, the wire being of a metal having a melting point close to that of the molten metal, and
10 having a diameter substantially smaller than that of the outlet;

C) flowing freely a jet of said molten metal out of said outlet hole, thereby forming an unbroken wire shaped body of said jet that is stabilized by said wire; the
15 rate at which the wire passes out through the outlet hole being substantially the same as or greater than the rate at which said jet flows out of the outlet hole;

D) cooling the unbroken jet of molten metal surrounding the wire and causing it to solidify around
20 the wire; and

E) collecting the wire and solidified surrounding molten metal.

2. A method according to claim 1 wherein said diameter of the outlet hole is substantially in the range 1.5 to 2
25 times greater than the dimension of the wire.

3. A method according to claim 1 or 2 wherein said wire is introduced into the bath through a pipe whose upper mouth is located above the upper surface of the bath, and



112

-18-

whose lower mouth is located adjacent said outlet hole.

4. A method according to claim 3 wherein said pipe is of ceramic material.

5. A method according to claim 3 or 4 wherein during
5 passage of the wire through the pipe it is cooled by a coolant within the pipe.

6. A method according to claim 5 wherein the coolant is liquid argon.

7. A method of manufacturing metallic wire products
10 substantially as herein described with reference to the accompanying drawings.

8. An apparatus for manufacturing metallic wire products by direct casting of molten metal, said apparatus comprising: a bath of said molten metal in a
15 container including a bottom in which is formed an outlet hole; wire supply means at least partially located above the container, for supplying wire through said bath and outlet hole, the supply means including wire having a melting point close to that of the molten metal, and a diameter _____



-19-

substantially smaller than that of the outlet hole, so that the molten metal of said bath can flow freely as a jet through said outlet hole around said wire; cooling means for cooling said molten metal

5 flowing out of said outlet hole to solidify a coating on said wire; and wire take-up reel means for coiling the wire with said solidified coat.

9. Apparatus according to claim 8 wherein said diameter of the outlet hole is substantially in the
10 range 1.5 to 2 times greater than the dimension of the wire.

10. Apparatus according to claim 8 or 9 in which said cooling means are located beneath said container, and include a cooling container for containing coolant in
15 liquid form the container having an upward opening and a sealing hole in its bottom to allow passage of the wire with molten metal through said coolant; and further including means for recirculating said coolant.

11. Apparatus according to any of claims 8 to 10 further
20 including a pipe arranged so that its upper mouth is located above the upper surface of the bath and its lower mouth is immersed in the bath adjacent the outlet hole in the bottom of the container, so that the wire can be introduced into said bath through said pipe; and wherein
25 the pipe is raiseable and lowerable and the lower mouth is sealably engageable against the container bottom so that the outflow of molten metal through the outlet hole can be controlled and cut off completely by the lower



114
-20-

- mouth sealing against the container bottom.
12. Apparatus according to claim 11 wherein said pipe is of ceramic material.
13. Apparatus according to claim 11 or 12 in which the
- 5 pipe is arranged to contain a coolant for cooling said wire as it passes through the pipe, the pipe including at least one opening adjacent its upper mouth through which the coolant can be supplied under pressure, and a seal for retaining the coolant in the pipe while admitting
- 10 passage of said wire.
14. Apparatus according to any of claims 8 to 13 further including means for generating magneto-hydrodynamic force fields adjacent said outlet hole to control the rate at which molten metal flows out through the outlet hole.
- 15 15. Apparatus according to claim 8 substantially as described herein with reference to and/or as illustrated in Figs. 1 and 2 or Fig. 1 as modified by any of Figs. 3 to 5 of the accompanying drawings.
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