Feb. 26, 1957 J. B. BRENNAN 2,782,473

CONTINUOUS CASTING METHOD AND APPARATUS

Filed March 20, 1953 3 Sheets-Sheet 1

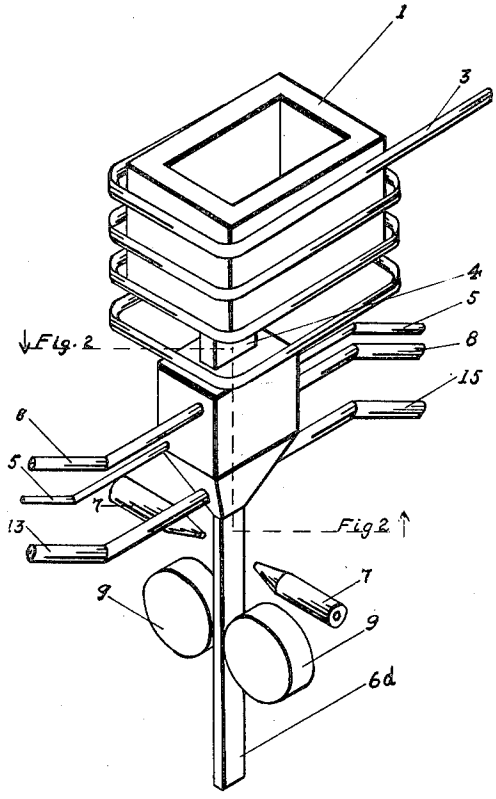


Fig. I

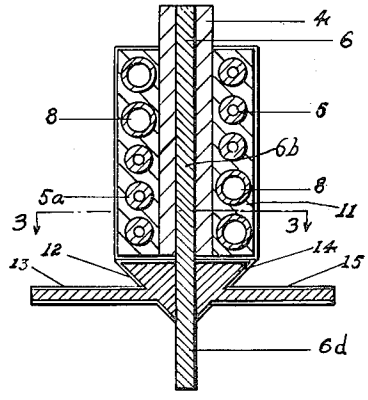


Fig. 2

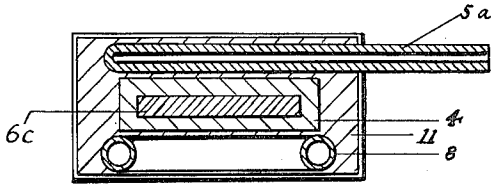


Fig 3

INVENTOR.
Joseph B Brennan
BY
West & Oldham
attorneys

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CONTINUOUS CASTING METHOD AND APPARATUS

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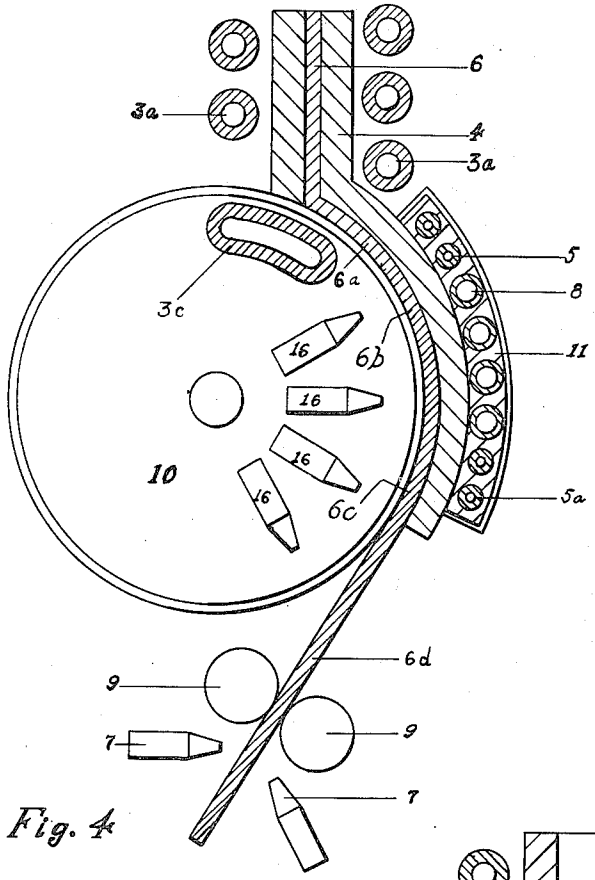


Fig. 4

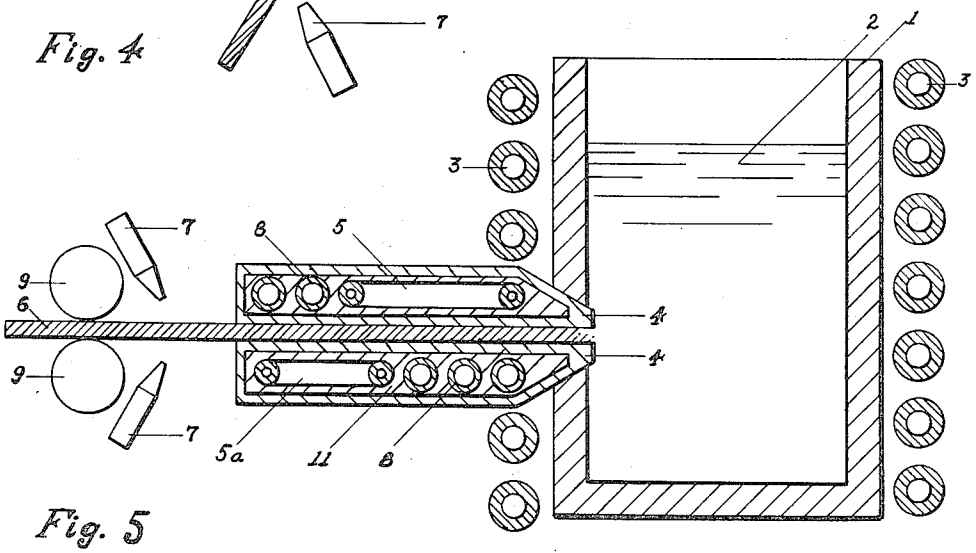


Fig. 5

INVENTOR.

BY Joseph B. Brennan

West & Oldham

attorneys

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CONTINUOUS CASTING METHOD AND APPARATUS

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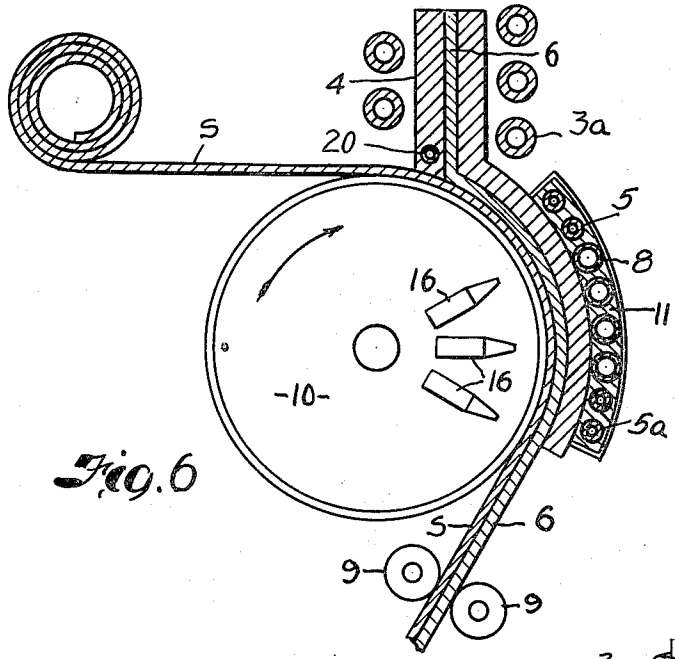


Fig. 6

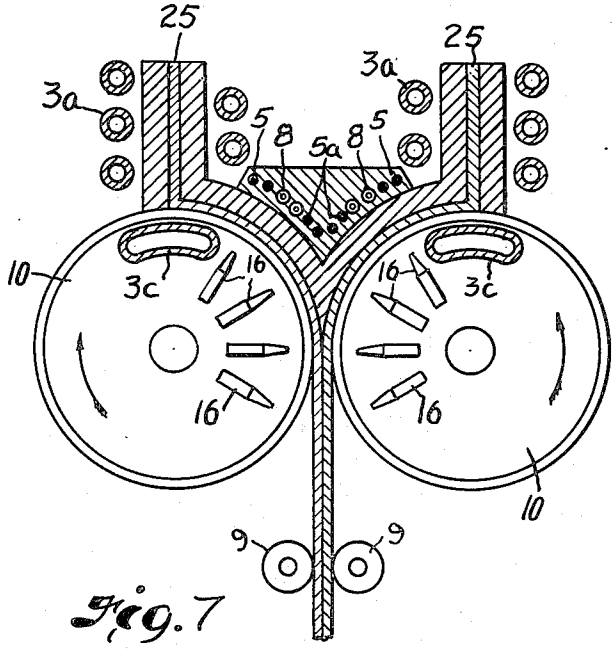


Fig. 7

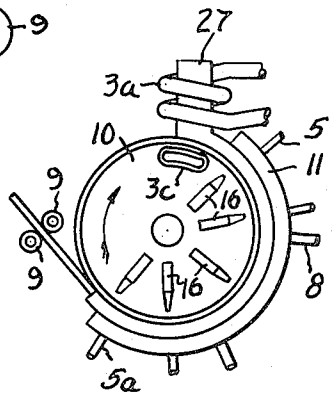


Fig. 8

INVENTOR.
JOSEPH B. BRENNAN
BY
Oberlin & Limbach
ATTORNEYS.

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2,782,473

CONTINUOUS CASTING METHOD AND APPARATUS

Joseph B. Brennan, Cleveland, Ohio

Application March 20, 1953, Serial No. 343,563

7 Claims. (Cl. 22—57.2)

This invention relates to continuous casting of molten materials normally solid but rendered liquid by heat to melt or render plastic materials such as metals, ceramics, or glass in tubes, rods, strips, or other shapes. This invention also relates to the lamination of such cast materials to one another or to other solid materials which are moved in contact therewith.

This application is a continuation in part of my co-pending application Serial No. 117,620, filed September 24, 1949, now abandoned.

According to this invention, molten metal streams are advanced from a crucible through an enclosing die so constructed that certain die contacting portions of the stream are solidified and other die contacting portions in the same cross-section are retained molten, plastic, or liquid.

The die is so designed that it can heat and chill simultaneously, or alternatingly heat and chill a given section of molten metal passing therethrough.

I have found that the sectional heating and chilling of the molten material being cast on a given section of the casting die has great advantages in that it permits application of a tension sufficient to effect steady withdrawal of the strip material at a constant rate without parting of the metal being cast in the heating and chilling zone due to the fact that a cross-sectional portion of the metal being cast can be maintained solid in this zone with the result that sticking in this zone, such as has been a detriment heretofore, is eliminated.

I have found that by solidifying only a portion of the exterior cross-sections of a strip being cast, and simultaneously chilling the same cross-sectional portion of said strip, the material being cast slips through the die readily and can be readily withdrawn therefrom without interruption or leakage due to the fact that at least a portion of the cross-section of the strip being cast is solid and has developed sufficient tensile strength in this section to prevent parting when pulled.

This solid and plastic section of strip being cast may be accomplished, for example, by:

1. Having only a part of the skin molten when the core is solid or plastic;

2. Having one die-contacting face portion of the strip being cast, plastic or liquid while the opposite side is solid;

3. Having a substantial portion of the cross-section liquid or plastic while the remainder of the cross-section is solid.

Other means of accomplishing the objects of this invention, whereby sticking in the casting die is eliminated due to partial exterior plasticity and partial exterior solidity of cross-section, will be evident from my disclosure to those skilled in the art.

Apparatus suitable for practicing this invention is disclosed in my pending application Serial No. 728,771, filed February 15, 1947, now abandoned and in my issued Patent No. 2,569,150, dated September 25, 1951.

It is possible according to my invention to vary the heating effect of high frequency currents so that, as the metal advances in the extrusion die, part of the exterior of said strip can be kept liquid or plastic and slippery while another exterior part thereof is solid and of relatively high tensile strength.

Other objects and advantages of the present invention will become apparent as the following description proceeds.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principle of the invention may be employed.

In said annexed drawings:

Fig. 1 is a view of apparatus suitable for carrying out this invention;

Fig. 2 is a vertical sectional view of the die of apparatus shown in Fig. 1 at line **2—2**;

Fig. 3 is cross-section of the die of Fig. 2 taken at line **3—3** thereof;

Fig. 4 is a section of another type of die having a moving supporting and carrying surface for the metal being cast;

Fig. 5 is a section of another type of apparatus and hot and cold die for carrying out this invention;

Fig. 6 illustrates an apparatus similar to Fig. 4 except showing a die for accommodating a solid metal strip to which the cast metal strip is to be laminated and including heating means to surface fuse the solid strip for the bonding of the molten metal thereto;

Fig. 7 is a laminating apparatus wherein two apparatuses similar to Fig. 4 are arranged so that the castings emerging therefrom are brought together in face-to-face contact for laminating the same; and

Fig. 8 is a modification in which the casting extends around a major portion of the periphery of the casting wheel so that, as the casting shrinks, it will better cling to the casting wheel so as to be driven thereby while the opposite face of the casting may be retained in slippery condition with a molten skin thereon.

Referring now more particularly to the drawings and first to Fig. 1, the apparatus there shown comprises a metal casting crucible **1** having molten metal therein kept at a constant level by any suitable feeding means (not shown) and a die **4** leading therefrom of thin rectangular interior cross-sections both heated by the surrounding high frequency coil **3**.

A portion of the die **4** is in the high frequency field of coil **3** which field is preferably in excess of 10,000 C. P. S. whereby the upper portion of metal strip **6** in die **4** is maintained liquid or molten, the adjacent portion is cooled on one side and then the other to plastic condition along the opposite, staggered cooling coils **8** and retained molten on the other side and then said one side along high frequency coils **5** and **5***a*, and the lower portion emerges from die **4** in heated, shape-retaining form.

The high frequency coil **5** may be placed, as hereinafter specified, progressively further from the face of the metal strip **6** being cast the nearer this metal strip comes to the end of the die **4** as the strip **6** advances.

This placing of the high frequency coil **5** permits shading of the surface heating effect giving a tapered solidification effect as the strip progresses, in conjunction with cooling coil **8** acting on the opposite side of strip **6** to solidify the strip **6** progressively as it advances. A porous die extension member **14**, as of tungsten, is attached to the lower exit end of said heating and cooling die **4** so that molten lead may be forced against the outside of the

strip 6 as it advances to lubricate, the lead being fed in and out of said porous die extension 14 by pipes 13 and 15.

Water sprays 7 regulate chilling of the metal strip 6 as it advances and the rolls 9 may be used to roll the strip to assume its final smooth solid state 6*d*.

Referring to Fig. 2 which is a cross-section on line 2—2 of Fig. 1, one portion, a relatively large portion, say 75% of the cross-section of strip 6 is liquid at the cross-section between high frequency coil 5 and cooling coil 8, and 50% of the cross-section 6*b* in the cross-section between high frequency coil 5*a* and cooling coil 8 is solid, whereas at 6*c* only 5%–10% of cross-section is plastic and at 6*d* the entire cross-section is solid after emergence.

The high frequency coils 5 and 5*a* may be wider spaced between the coils near the exit of the die 4 or their turns may be spaced away from the strip at a preferably constant angle as the coils 5 and 5*a* extend along the strip 6 being cast so that the magnetic surface heating effect progressively diminishes as the exit of the die 4 is approached by the strip 6 being cast and thereby the thickness of the layer of molten liquid or plastic metal on one side portion of the strip is lessened so that, when the strip 6 emerges from die 4, it is solid enough, at least exteriorly, that it will not change shape appreciably after emergence except for additional shrinkage effected by fluid coolant sprays 7.

A constant level of metal and a constant pressure on said head of metal in crucible 1 is preferable to constant performance of the apparatus. A constant head is not essential, although desirable, when the casting apparatus includes a wheel as in Figs. 4 to 8, for example.

Apparatus such as described in my above-mentioned application and patent may be used to effect the desired pressure on the metal in crucible 1 and to provide constant head therefor.

Also, the head of metal in crucible 1 may be kept constant, if desired, by feeding with a ladle manually operated.

The cooling coil 8 in Fig. 2 may be set in ceramic or metal or graphite, and may be also set at an angle to the axis of metal strip 6 being cast so that its turns are further away near the zone where the cross-section is completely molten and gradually and preferably are nearer as the strip advances to the exit.

Multiple cooling coils 8 each of different cooling capacity may be substituted for a single coil, if desired. The tapered cooling effect on each cross-sectional portion is essential, however, as well as the tapered heating effect, due to the spacing of the high frequency coils 5 and 5*a* in Fig. 2. The cooling effect of coils 8 increases in cross-sectional effect as the strip advances and the depth of heating effect by high frequency coils 5 and 5*a* is progressively diminished as the strip being cast advances.

Fig. 3 is a cross-section view taken as indicated at 3—3 on Fig. 2 wherein 5*a* is a high frequency surface heating coil in preferably dielectric casing 11 alongside graphite die 4 and having cooling coil 8 on opposite side of graphite die 4 whereby one exterior portion of a cross-section 6*d* of metal is kept plastic or molten as previously explained.

Fig. 4 illustrates another arrangement suitable for differentially maintaining one part of the cross-section of the strip 6 being cast in plastic, liquid, or molten condition indicated at 6*a*, so that it is slippery externally over a part of its outside area while another portion of its cross-section and outside area at 6*a* is solid adjacent moving roll 10 and of higher tensile strength. The reference characters 6*b*, 6*c*, and 6*d* denote the states of the metal as it flows through the die, at 6*b* about 50% of the metal being solid, at 6*c* about 5–10% of the metal being plastic, and at 6*d* the entire cross-section of the metal being solid.

The strip is cast over a grooved moving roll 10 which defines part of the die through which the strip 6 is cast and the other part of the die 4 over the roll 10 in Fig. 4 is adjacent and has the high frequency coils 5 and 5*a*

therein or adjacent thereto and arranged to keep an exterior section of the strip 6*a* being cast slippery for a portion of its passage through the cooling zone. Fluid coolant sprays 16 in Fig. 4 chill the roll 10 progressively in the section adjacent the metal strip 6 being cast by extracting heat through the walls of the heat conducting roll 10.

A high frequency coil 3*a* in Fig. 4 is supplied as part of the apparatus around die 4 so as to assure that, when the molten metal hits the exterior of the wheel 10, it will be liquid in this zone when starting through the die to be solidified. Coil 3*a* may have an extension on the hollow interior of the wheel 10 or a separate high frequency coil 3*c* or other heating means can be applied here to keep the molten material being cast in the starting zone liquid. Other heating means than high frequency can be used to take the place of coils 3, 3*a*, and 5 in Fig. 4 for the purposes of this invention provided that the tapered, sectional, molten, and solid characteristics of the strip are adhered to in desired locus or locii. Frequency as high as 20 mergacycles may be used for surface heating.

The strip should be exteriorly partly solid so as to maintain its shape upon emergence from die defined by the roll 10 and shoe of die 4 thereover.

Fig. 5 illustrates a further modification of the principles and apparatus of this invention wherein the crucible 1 having the constant level molten metal 2 therein has a solid bottom with the die 4 extending out of its side. The high frequency coil 3 extends outside the die 4 so that it heats the die 4 and the metal strip 6 therein being cast.

An additional high frequency surface heating coil 5 extends along the strip 6 in die 4 in Fig. 5 preferably at an angle thereto or in any case so as to keep a portion of the die contacting metal being cast mobile.

The die 4 is end tapered to fit into the wall of crucible 1 without metal leakage at this joint.

The lower part of the die 4 has cooling coils 8 extending along the strip 6 being cast so as to maintain a portion of the cross-section of the strip 6 solid and the high frequency coil 5 on the opposite side of the strip 6 maintains a portion of the same cross-section mobile until the end of the die is reached by the strip 6. As in Fig. 1, cooling coils 8 and heating coils 5*a* may be employed adjacent the exit end of die 4 in opposite relation to the casting as compared with coils 8 and 5 adjacent the inlet end of die 4.

Cooling sprays 7 further chill the metal, and rolls 9 assist in withdrawal.

High frequency coil 5*a* in dielectric packing in case 11 serves to render previously solidified exterior surface of strip 6 mobile and to relieve sticking, and an added section of cooling coil 8 may be placed above coil 5*a* as shown, to solidify that side.

According to this invention, a solid section of the metal being cast extends through a space along the inside of the die and in contact therewith through which die said metal is being cast from the liquid zone to the exit end of the forming die. The metal is fed to the liquid zone as fast as it is withdrawn and sensitivity of necessary coordination between rate of withdrawal and solidification is lessened.

The cooled portion of the cross-section having tension applied thereto assists in moving the liquid plastic or molten portion of the cross-section and the plasticity of the exterior, i. e., the liquid, plastic, or molten portion of the cross-section lessens or eliminates the sticking tendency of the strip rod or tube being cast.

Heat may be added right up to the exit end of the die block 4 by the surface heating coils. Solidification on this previously heated portion of the cross-section being effected just prior to or at emergence of the metal strip from the die by sprays 7.

For a metal strip or rod 1/16" thick as of copper solidification on the previously molten side need be only effected for a short distance inside the die and adjacent the end thereof such as, for a distance equal to 1/200 of

the length extruded per minute, using a cooling chamber or coil to flow water at 70° F. at 70 lbs. pressure therethrough, this in addition to the cooling effect had by the opposite face cooling and the spray coolant conductive effect at the exit. Thus, the heat extraction on the heated plastic section is rapid and for a short distance related to the length extruded per unit of time.

A slight plastic skin on the previously heated side of the strip may be present upon emergence from the die, but this will only extend for a depth of a very few thousandths of an inch inward the surface thereof and is immediately chilled by the coolant spray **7** and does not interfere with securing a smooth surface.

The end of the die or a short section thereof at emergence may be porous and may be made of porous graphite or tungsten or aluminum oxide or other suitable material to permit forced lubrication therethrough as of molten lead which acts as additional coolant as well as lubricant.

The herein described apparatus can be used to extrude and shape other materials which are solid at normal temperatures and liquid or molten at highly elevated temperatures, such as glass, ceramics, and thermoplastics.

Adjacent wedge-shaped sections are formed in the simultaneous heating and cooling zone having the sharp ends of the wedges pointing in opposite directions, one sharp end pointing away from the direction of movement of the metal being cast, and one sharp end pointing in the same direction as the strip metal being cast, one longitudinally wedge-shaped section being solid and adjacent wedge section plastic.

In casting flat, rectangular, or hexagonal, or round rods or strips or tubes, multiple surrounding alternate exterior sections can be surface heated by means of spaced high frequency tubes extending parallel to the axis of the casting, preferably at an angle thereto having multiple interposed cooling sections of the die therebetween, if desired, to accomplish the purposes of this invention. Thus, the casting will have multiple alternate exterior chilled and exteriorly plastic sections extending therealong and thereabout instead of just two sections as above described.

The grain growth is made fine by use of this apparatus and process due to the rapidity of cooling and rate of extrusion being preferably in excess of 18 feet per minute for a strip 1/16" thick.

The resultant tensile and flexibility of the product are high due to the fine grain structure secured.

Bearing strip may be produced with this apparatus wherein the grain growth extends at substantially 90° to the length of the strip produced and the grain length is toward the flat face resulting in great wearing qualities as much as ten times that obtainable with heterogeneous grain growth material.

In casting tubes and rods, an exterior facial portion is kept plastic and another exterior facial portion is kept solid in the same cross-section as the extruded metal advances in the die until, when the rod or tube is adjacent the end, when the final cooling is effected just prior to or upon emergence. A few thousandths depth of plastic metal upon emergence in one exterior facial section (and also on an interior facial section of a tube) is not objectionable since it is immediately solidified upon emergence by cooling sprays inside and outside. The very slight irregularity in surface which may result is not objectionable.

However, complete solidification to the section being cast can be had if additional cooling is provided for a length of die section say 1/10 of the feet per minute rate of extrusion all around the exit end of the die.

As a specific example of my apparatus and method, I have obtained excellent results in the casting of bronze strip 1" by 1/16" with the apparatuses of Figs. 1, 4, and 5. For casting bronze the crucible **1** is preferably made of graphite and may be of any size. In one example, the crucible **1** was 8" by 8" cross-section size and 10" deep and had walls about 1/2" thick. Wrapped around said crucible was about **11** turns of a high frequency coil **3** adapted for connection with a high frequency generator (10,000 C. P. S.). The upper portion of the die **4** for said 1" by 1/16" strip was of about 6" length (including, in the case of Fig. 4, the arcuate wheel embracing shoe) of which about 4" was subject to the influence of coil **3** (Figs. 1 and 5) and coil **3***a* (Fig. 4). The die **4** was made of graphite and had a wall thickness of about 1" and along opposite sides of the die, in staggered relation thereto, were heating coils **5** and **5***a* and cooling coils **8**; said coils **5** and **5***a* in Fig. 2 each extending along about 4" of the length of die **4** and spaced from the die passage inside walls approximately 1 1/8", and being connected to a 500,000 C. P. S. high frequency generator; and said coils **8** being similarly spaced and adapted to have circulated therethrough a coolant such as water at a temperature of 60° F. and at a pressure of 35 p. s. i. at a rate of about 10 gals./min.

When casting bronze, heated to 2300° F. in crucible **1** and maintained at a pressure head of 1 p. s. i., 1" by 1/16" strip can be pulled by rollers **9** at a rate of 120 in./min. from the bottom end of die 4. The coils **8** cool the metal as it passes through the die **4** to impart tensile strength thereto, and the coils **5** and **5***a* have a surface heating effect to alternately heat the sides of the cast strip to provide a slippery molten skin thereon. The molten lead at a temperature of 650° F. has a cooling effect and serves as a lubricant. The cast strip as it issues from the die **4** is at a temperature of about 800° F. and a pull of about 20 lbs. may be exerted on the issuing strip without causing parting thereof in the die.

In the case of the Fig. 4 apparatus, the additional coil **3***c* maintains the metal molten at the start of the die passage as defined between wheel **10** and the arcuate shoe of said die **4** and it has been found that coolant sprays **16** should cool the outer wall of wheel **10** to about 1,000° F. when casting bronze at a temperature of 2,300° F. In one example, the wheel **10** was of graphite and had a diameter of 6" and a wall thickness of 1/2", the arcuate shoe extending around about 1/4 the circumference of said wheel. The heating coils **5** and **5***a* (500,000 C. P. S.) each extended about 4" of the die passage length and were spaced 1/8" therefrom, and again as in Fig. 2, the cooling coils **8** employed water at 60° F. and circulated at 35 p. s. i. and were spaced about 1/4" from the die passage and extended along the die passage for a length of about 4". By driving said wheel **10** at a rate of 6 2/3 R. P. M. or a peripheral speed of 120 in./min., the same results were obtained as in Fig. 2. Instead of driving said wheel **10**, the rolls **9** may be power driven to pull the casting, and the frictional engagement of the strip with wheel **10** will rotate the same in its bearings. In any event, it is not here necessary to heat the inner surface of wheel, except for starting, because the casting and wheel move in unison whether the rotation of said wheel is effected by either power drive means or by pulling of the strip in contact thereover.

With further reference to Fig. 4, it is possible to omit the cooling coils **8** and to employ just the heating coil **5**, with or without coil **5***a*. Moreover, sprays **16** or equivalent cooling means may be dispensed with in some cases where air cooling is sufficient and similarly coil **3***c* is not always required because at relatively high speeds (for example 150 R. P. M. and greater), the chilling effect at the die inlet is not enough to prematurely freeze the metal in the hot-forming zone after the casting has been started.

The apparatus of Fig. 6 is generally similar to that of Fig. 4 except that the die **4** has been modified to accommodate a solid metal strip S therein for movement around the casting wheel **10**. A high frequency or like heating coil **20** of, for example 15 megacycles, is preferably disposed at the inlet end of the die passage, as shown, so that the outer surface of said solid metal strip will be heated to bonding temperature, viz. to its melting point

or thereabove, which temperature is preferably greater than the melting point of the molten metal to be applied thereto. Thus, it can be seen that, when the wheel is rotated and the strip S is moved therewith, the molten metal in the die will be formed on said strip S and thereby form a laminated product which comprises the strip S and the cast strip **6** bonded together. The apparatus otherwise is generally similar to that in Fig. 4; and, therefore, repetition of the details is not deemed necessary. As a specific example, the molten metal may comprise bronze which is at a temperature of about 2,300° F. when it first enters the arcuate portion of the die passage, and the strip metal S may be of cold rolled steel and only the outer skin thereof is heated to a temperature of approximately 2,300° F. by means of the high frequency coil **20**. In said one example, the strip S was of dimensions 1" by 1/20" and the casting thereon was 1" by 1/32" and with a pressure head of 1 p. s. i. such composite article was continuously produced at a rate of 144 in./min.

The apparatus of Fig. 7 essentially comprises two of the Fig. 4 or like apparatuses arranged so that two metal castings are joined together along their molten faces to form a laminated casting **24**. The dies **25** are like the dies **4** in that they have arcuate shoe portions embracing the respective wheels **10**. Thus, the metals bronze and steel, for example, may be bonded together without any change in principle of the equipment as compared with Fig. 4.

In Fig. 8 is shown a modified apparatus differing from Fig. 4 only in that the cast strip and the die **27** embrace the wheel **10** for a substantial extent, such as 180° or more, for example, whereby as the cast strip solidifies and shrinks, it will cling to the wheel for movement in unison therewith. In this way, it is not necessary to pull on the casting by rolls **9**, or if rolls **9** are used for pulling, the wheel **10** may be an idler, in which event the large extent of the surface contact with the cast strip will prevent parting of the casting.

Other modes of applying the principle of the invention may be employed, change being made as regards the details described, provided the features stated in any of the following claims, or the equivalent of such, be employed.

I therefore particularly point out and distinctly claim as my invention:

1. Continuous casting apparatus comprising a die provided with an elongated passage therethrough for the flow of molten material thereinto from one end and therethrough for discharge from the other end in the form of a continuous shape-retaining casting of cross-section the same as that of said passage, said passage having a wall portion lengthwise co-extensive therewith relative to which a surface portion of the molten material flows in contact, means for maintaining the entire cross-section of the flowing material in molten condition in a portion of the length of such passage from such one end toward such other end, temperature modifying means along such wall portion for respectively extracting heat from the molten material in contact therewith to progressively cool such surface portion to less than the melting point of the material through a substantial portion of its cross-section thickness to thereby impart tensile strength to the material as it continues to flow toward such other end and for heating such surface portion of the previously cooled material to form a thin, molten, slippery skin for facilitating passage of the material through said die and for effecting a smoothening action by the sliding contact of such surface portion of the material with said wall portion.

2. The apparatus according to claim 1 further characterized in that an opposite wall portion of said passage is moved in unison with the opposite surface portion of the material in contact therewith, and in that cooling means are provided along said opposite wall portion to progressively cool such opposite surface portion of the material during successive cooling and heating of such surface portion of the material as aforesaid.

3. The apparatus according to claim 1 further characterized in that other temperature modifying means are located along an opposite wall portion of said passage with which the opposite surface portion of the material is in contact, said other temperature modifying means being disposed relative to the first-named temperature modifying means so that such opposite surface portion of the material opposite to the cooled surface portion is maintained in molten condition and that such opposite surface portion of the material opposite to the molten, slippery skin is cooled to solid condition through a substantial portion of the cross-section thickness of the material.

4. The method of casting which comprises the steps of laterally confining a longitudinally moving stream of molten material, heating the material to maintain the entire cross-section of a portion of the length of the stream in molten condition, progressively cooling one surface portion of an adjacent portion of the length of the stream to less than its melting point through a substantial portion of its cross-section thickness to thereby impart tensile strength thereto, and heating the cooled, solidified side of the stream to form a molten, slippery skin thereon for facilitating movement of the stream while laterally confined.

5. The method according to claim 4 characterized further in that a surface portion opposite to the cooled and heated surface portion of the stream is heated and cooled for maintaining said opposite surface portion molten while said one surface portion is solidified and for solidifying said opposite surface portion through a substantial portion of the cross-section thickness of the stream while said one surface portion has a molten, slippery skin, whereby said one and opposite surface portions of the stream are subjected to a sliding, smoothening action longitudinally thereof.

6. A method for the continuous casting of metal strip which comprises the steps of laterally confining a longitudinally moving stream of molten metal by causing flow thereof through a die passageway, preshaping by hot-forming the entire facial portion of the moving stream as it advances through the die passageway, thereafter extracting heat from and adding heat to opposite facial portions of the same cross-section of the pre-shaped stream as it advances through the die passageway to effect solidification of one facial portion while the other and opposite facial portion is maintained labile, thereafter extracting heat from such labile facial portion whereby the latter is solidified, and continuously withdrawing the solidified strip from the die passageway.

7. The method of claim 6 wherein such initially solidified one facial portion is subsequently heated to labile condition during the advance of the metal through the die passageway and at the same time that such other and opposite facial portion is being solidified.

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