Fig. 28. Fig. 29. Fig. 27.

Fig. 30.

Thickness of steel strip (m)

Length of longest side of 'case' (L)
Other processes which have been proposed but never widely used are the continuous casting of metal using metal strips or bands which move downwardly to form a continuous casing. The molten metal is poured into the casing formed by the strips or bands where it solidifies with the strips or bands. Further, a process has been proposed wherein a tubular casing is formed by a strip and molten metals such as copper and brass are poured in the casing. However, many difficulties have occurred with the use of these processes in steel casting because of a low heat conductivity, a high melting point and a high specific gravity of steel. The primary problem is the complete enclosing of the molten metal. This is of extreme importance since the outside strips or bands are liquid cooled and damage to the casing will occur if any of the cooling fluid should penetrate into the solidifying casing. Also, if the encasing strips or bands are not sealed tight, leakage of the molten steel may be appeared. An additional problem is that the joints of the metal strips or bands must be of sufficient strength to prevent possible separation due to the static pressure of the poured molten steel. Yet another problem is that bulging of the steel strips or bands will occur unless they are of sufficient thickness. This will limit the casting speed and thereby reduce productivity.

Therefore, it is a primary object of the present invention to provide a process and apparatus for the continuous casting of steel which will overcome all of the above as well as other problems and deficiencies of previously used casting methods.

Another object of the present invention is to provide a process for making an indefinite length of steel strand from molten steel with a high productivity rate.

A further object of the present invention is to provide an apparatus for the production of steel strand having a good surface quality in an inexpensive and highly efficient manner.

Another object of the present invention is to provide an apparatus for forming a continuous casing which will be completely sealed to prevent any leakage of the molten steel.

Still another object of the present invention is to provide a process and apparatus for making a metal clad object having a core made of a metal such as steel.

A further object of the present invention is to provide an apparatus which is of relatively simple construction and easy to manufacture, which is automatic and rapid in its operation, and which is well adapted for the purposes described.

According to the present invention, the foregoing and other objects are attained by providing a continuous casting process and apparatus wherein molten steel is directly poured into a polygonal tubular hollow casing (hereinafter referred to as "continuous case") of a desired section which is formed by a plurality of steel strips or bands. This "continuous case" operates to define the cross section of the steel strand to be continuously cast and to transmit outwardly the sensible heat of the molten steel. In this regard, the continuous case functions like a mold but travels together with the steel strand, and, therefore, the case itself becomes an outer skin of the strand.

The specific nature of the invention as well as other objects, uses and advantages thereof will clearly appear from the following description and from the accompanying drawings, in which:

FIG. 1 is a side elevation view, partly in section, of an apparatus of the present invention;
FIG. 2 is a front elevational view, partly in section, of the apparatus of the present invention.
FIG. 3 is a perspective view of the continuous casting apparatus of the present invention; FIG. 4 is a horizontal sectional view of the first forming stage;

FIG. 5 is an enlarged view of a portion of FIG. 4 clearly depicting the first forming operation;

FIG. 6 is a horizontal sectional view of the strips forming the continuous case at the first forming operations without showing the forming apparatus;

FIG. 7 is a horizontal sectional view of the second forming stage;

FIG. 8 is an enlarged view of a portion of FIG. 7 clearly depicting the second forming operation;

FIG. 9 is a horizontal sectional view of the strips forming the continuous case at the second forming operation without showing the forming apparatus;

FIG. 10 is a perspective view of a guide assembly used in the apparatus of the present invention;

FIG. 11 is a vertical sectional view taken along the line \(x-x\) of FIG. 10;

FIG. 12 is a vertical sectional view taken along the line \(y-y\) of FIG. 10;

FIG. 13 is a horizontal sectional view of the seam welding operation;

FIG. 14 is a horizontal sectional view of the strips forming the continuous case after the welding operation;

FIG. 15 is a sectional view similar to FIG. 11 showing a modified guide assembly;

FIG. 16 is a sectional view similar to FIG. 12 showing another view of the modified guide assembly;

FIG. 17 is a horizontal sectional view showing a modification of the forming rolls consist of single stage;

FIG. 18 is an enlarged view of a portion of FIG. 17 clearly depicting the forming operation using the forming rolls of FIG. 17;

FIG. 19 is a horizontal sectional view of the strips forming the continuous case at the forming operation using the forming rolls of FIG. 17;

FIGS. 20–22 are horizontal sectional views showing various forms of multiple lapping of the edges of the strips forming the continuous case;

FIG. 23 shows the successive forming steps of the multiple lapping of FIG. 20;

FIGS. 24–29 show various forms of mechanically joining the edges of the strips forming the continuous case; and,

FIG. 30 is a graphic chart showing the relationship between the production rate and the length of the case in cross section and the thickness of the strip forming the continuous case.

Referring now to the drawings, as shown in FIGS. 1–3, the molten steel is continuously poured from a ladle through a trough 2 into a rectangular continuous case 5 formed by steel strips 3, 4, and 4. Although this preferred embodiment uses four strips to form a rectangular continuous case, it will be appreciated that more or fewer strips will be required depending on the cross section desired for the continuous case.

The continuous case 5 filled with molten steel therein is supported at the outer surface thereof by a plurality of roller supports 6 and 7 while being cooled by high pressure water discharged from a plurality of spray nozzles (not shown) provided on the conduits 8 and 9 of the cooling means. The molten steel 10 in the continuous case 5 is cooled by the cooling means due to its surface contact with the inside surfaces of the continuous case 5. As shown in FIGS. 1 and 2, the molten steel 10 is solidified from the outer surfaces in contact with the continuous case 5 inwardly to the core thereof to form the steel strand 11.

The steel strand is withdrawn by a suitable mechanism (not shown) in synchronism with the downward movement of the continuous case 5. The mechanism to withdraw the steel strand may also be used for moving the continuous case 5 downward or two separate mechanisms can be provided. As the steel strand and the continuous case 5 are being withdrawn either the case 5 can be pulled off the steel strand by suitable means or the steel strand and case 5 can be left joined.

A fundamental idea of the present invention will be obtained from the above description. In carrying out the present invention, it is understood that the following conditions and requirements will be met.

First, it is required that each joint of adjacent strips which form the continuous case be tightly sealed to prevent the molten steel from flowing outward or the cooling water from penetrating therein. If the tightness of the joint seals is defective permitting cooling water to penetrate into the continuous case, the quality of the steel strand would not only be lessened but it would give use to the danger of an explosion. Further, as is obvious, the flowing out of the molten steel would produce a condition requiring stoppage of production.

Second, each joint of adjacent strips should be of sufficient strength so that the joints will not fail and separate due to the ferrostatic pressure of the poured molten steel.

Third it is necessary that the sheet thickness of the steel strips used for constructing the continuous case should be sufficiently thick to prevent the case from bulging outwardly. Any slight bulging would make it impossible to maintain the desired cross section of the steel strand and further, it would lead to the breakage of continuous case.

Tests have shown that the sheet thickness will be limited by the continuous casting speed (withdrawal speed) and other operating conditions such as section dimension. The relationship between the withdrawal speed and the sheet thickness is shown in the following empirical formula:

\[ V = \frac{6.0 \times 10^5}{L^2 (0.972 + 0.55 m)} \]

where

\[ m = \text{sheet thickness of the strip for forming the continuous case, cm.} \]

\[ L = \text{length of the longest side of the continuous case in cross section, cm.} \]

\[ V = \text{withdrawal speed of the steel strand, cm./sec.} \]

From the formula, it is seen that the larger the section of steel strand and the thinner the sheet thickness of the steel strip, the smaller the possible maximum speed of withdrawal. FIG. 30 is a graphic chart showing the allowable maximum value of the withdrawal speed (V) of steel strand at various lengths (L) of the longest side of continuous case in cross section for different steel strip thicknesses (m).

On pouring the molten steel, it has been found that there will arise turbulence of the molten steel due to the pouring stream thereof and a solidifying thin shell will be washed off. Sometimes, this washing off may attack the continuous case. In this event, the greater the strip thickness, the less the danger of breakage.

Therefore, it follows that the thicker the steel strip, the safer its operation. However, with the increase of sheet thickness, the consumption of steel strip will be increased with the result that it would be not only economically disadvantageous, but also the forming and joining of the continuous case would be difficult. It has been found that the thickness of the steel strip should be in the range of 0.2 to 3.2 mm. and preferably 0.6 to 1.6 mm.

The outside of the continuous case is sprayed with a cooling fluid such as water supplied by the cooling means. It will be apparent that the volume of cooling water employed depends upon the thickness of the steel strip, the cross section, and the withdrawal speed of the steel strand.

Tests have shown that approximately 0.2 ton of water per square meter of the continuous case in one minute is required for proper cooling. This volume of water is required because the temperature of the surface of the continuous case should not be higher than the
temperature of 600° C, when the molten steel having the temperature of 1500-1600° C, is poured into the continuous case, and further, the undesirable expansion of the continuous case must be limited.

Discussing now more specifically the preferred embodiment of the invention illustrated in FIGS. 1-14, two steel strips 3, 3 of relatively wide sheet and two steel strips 4, 4 of relatively narrow sheet are utilized to form a continuous case 5 having a rectangular cross section. In this embodiment, the apparatus used in connection with the strips 3, 3 or 4, 4 is symmetrical, and the working process in connection with the strip joints is also symmetrical, and therefore, only one strip or one strip joint will be discussed to simplify the description.

The wide strip 3 is continuously supplied from a reel 13 where it passes through a pair of pinch rollers 14 and a plurality of side guides 15 into a space between a deflector roll 16 and an upper curved portion 18 of a guide assembly 17 whereby the strip 3 is deflected by the deflector roll 16 in a vertical downward direction. As shown in FIGS. 10 to 12, the guide assembly 17 comprises two duplicate sections each having a pair of upper curved portions 18, a pair of wide vertical portions 24, a lower curved portion 31, a narrow vertical portion 39 and a protector wall 100. The guide assembly 17 is preferably formed in two sections to simplify construction and to permit relative adjustment between the sections to aid in accommodating the steel strips 4. The guide assembly protects the forming means from any splashing of the molten steel as it is being poured into the continuous case 5. The guide assembly also prevents any splashing of the molten steel on to the inner surfaces of the continuous case 5 which would tend to roughen the inner surfaces of the continuous case 5.

In addition to deflecting the wide strip 3 vertically downward the deflector roll 16 also is part of the first forming stage 22 shown in more detail in FIGS. 4 and 5. The deflector roll 16 comprises a cylindrical middle portion 19" and two frusto-conical portions 19, 19, Cooperating with the deflector roll 16 as a pair of forming rolls 21 with frusto-conical portions 20. The frusto-conical portions 19, 19 on roll 16 are providing a gap between the deflector roll 16 and the wide vertical portion of the guide assembly 17 to attain an accurate forming of the strip 3.

From the first forming stage 22, the pre-formed strip 3 with the flanges 23, 23 as shown best in FIG. 6. To make this forming angle as large as possible would be advantageous for the subsequent forming steps, however, the initial forming bend is limited by the mechanical properties of the steel strip, the sheet thickness and the diameter of the forming rolls. It has been found where pre-forming with deflecting is carried out, a bending angle up to approximately 75° can be achieved easily with the flange width preferably in the 10 to 20 mm. range. In this forming step, the strip 3 passes through a gap between the wide deflector roll 16 and the wide vertical portion of the guide assembly 17 to attain an accurate forming of the strip 3.

In the second forming stage 27, the narrow deflector rolls 25, 25 and wide forming rolls 26, 26. Narrow steel strip 4 is continuously supplied from a reel 28 between pinch rolls 29 and side guides 30 into a space between narrow deflector roll 25 and the lower curved portion 31 of the guide assembly 17 where the strip 4 is deflected to a vertical into second forming stage 27 to meet preformed strip 3.

In the second forming stage 27, the narrow deflector rolls 25 comprise a cylindrical body the axial length of which is equal to the width of narrow strip 4. The wide forming roll 26 comprises a cylindrical body 33 and a cylindrical body 34 of reduced diameter at each end of said cylindrical body 33. The edge of narrow strip 4 together with the partly bent flange 23 of wide strip 3 is introduced in lapped relation into the gap between the roll surface end of the narrow deflector roll 25 and the annular end 37 of the wide forming roll 26. As a result, the flange is bent to an angle of approximately 90° whereby the flange 23 and the end of strip 4 are lapped to form a protruded lapped portion or lapping 38. All during this operation, the strips 3 and 4 are accurately aligned by the vertical portions 34 and 39, respectively, of the guide assembly 17.

The four strips 3, 3 and 4, 4 form a rectangular body with four protruded lappings 38, the cross sections of which is clearly shown in FIG. 9. To form sealed joints at lapping 38, the lapping 38 must be completely sealed together to prevent penetration of the cooling water or outflow of the molten steel.

In FIGS. 1 to 3 and 13, there is shown the preferred embodiment of using seam welding to seal the lappings 38. The welding means 40 comprises a seam welder 41 at each corner.

Each seam welder 41 has a pair of rotary electrodes 42 and 43 and an air cylinder 44 which urges one electrode 42 toward the other electrode 43. A pair of holding rolls 45 are provided immediately above the rotary electrodes to hold the lappings 38 tightly. The four lappings 38 are pressed and electrically welded in a vertical direction as they pass between rotary electrodes 42 and 43. The rotary electrodes 42 and 43 may or may not be driven. Thus, the completely sealed continuous case 5 of prescribed cross section as shown best in FIG. 14 is formed from four steel strips 3, 3 and 4, 4.

It will be understood that the above description is of a preferred embodiment for making a continuous case 5. However, the invention is not limited to this embodiment and may be carried out by the use of certain modifications which are described below.

The cross section of the continuous case 5 may be of any suitable polygonal shape besides the preferred rectangular shape. The number of sides of the polygonal cross section to be formed will determine the number of steel strips required.

In order to obtain the perfectly sealed continuous case, it is necessary to use a steel strip free from any variations in sheet width and which will be correctly aligned on the deflecting and forming rolls. To this end, the edges of the strip should be trimmed in advance of forming preferably by providing a side trimmer (not shown) in the processing line as the strip leaves the reel. In addition, the use of side guides or other types of edge position controllers are essential for proper alignment of the strip.

In the above-described embodiment, the deflector roll 16 performed a deflecting function as well as a forming function. This dual function was used in order to make the distance between the molten steel level in the case and the tundish nozzle as short as possible. It will be apparent to one skilled in the art that the deflector roll may be separate from the forming roll. If made separate, the deflector roll need not be a rotatable roll but may be a fixed curved member. The roller supports 6, 7 may also be fixed curved surfaces and in many instances the support 7 may be omitted for the narrow width steel strip 4.

In the guide assembly of the preferred embodiment, each section included the wide vertical portion 24 and the narrow vertical portion 39 formed integral with each other. It will be appreciated that these portions 24 and 39 can be separately formed since each portion deals with a different steel strip.

It has been found that the proximity of the guide assembly 17 to the molten steel can sometimes produce heating problems which can affect the guiding elements of the assembly. To prevent this overheating problem, there is shown in FIGS. 15, 16 a guide assembly 47.
which is similar in all respects to guide assembly 17 having upper curved portions 18', wide vertical portions 24' and narrow vertical portions 39' with the addition of a water jacket 46 having piping 46' to circulate the cooling water.

There is shown in FIGS. 17, 18 a forming assembly 48 which will simultaneously perform the deflecting and forming operations to produce a continuous case 5 having a modified form of lapping. In this modification, the edges of strips 3 and 4 are bent at an angle of 45° to form flanges 49 and 50 whereby the lapping 51 as best shown in FIG. 19 is produced. The forming assembly 48 consists of wide strip rolls 54 having frusto-conical portions 52 at its ends and narrow strip rolls 55 having frusto-conical portions 53 at both ends. This forming assembly 48 can attain an operation of deflection and formation in a single step. In the single step flange forming, a bending angle in the range of 15° to 75° is preferred.

In place of the above mentioned single lappings, double lappings 59, 60 and 61 shown in FIGS. 20 to 22 are easily formed. For example, in reference to the double lapping 59, a series of forming assemblies, illustrated in FIG. 23, may be utilized.

Various designs of forming assemblies can be used depending on the properties and thickness of the steel strips, the cross section of the continuous case, and the type of lapping desired.

In the preferred embodiment discussed above, the seam welding by electric resistance is shown, although any welding process, such as fusion welding, pressure welding and brazing may be employed. However, the seam welding method is the most suitable method for the high speed continuous welding required, to firmly seal the lapping together, other various mechanical joining methods may be used in addition to the welding procedure already discussed. Several examples are shown in FIGS. 24 to 29. FIG. 24 shows the formation of a joint 63 by bending the double lapping 59 at an angle of 90°. FIG. 25 shows a mechanical joint formed by placing a groove in the double lapping 59 with a set of grooving rolls 64 and 65.

Another joining method shown in FIG. 26 can be applied to both single and double lapings. In addition to the steel strip for use in the continuous case, a narrow steel strip 67 having notches 68 is formed into a V-shape by a series of rollers 69, 70 and a guide member 71 whereby it surrounds a lapping joint 72. A series of rollers 73 and 74 apply pressure to steel strip 67 to obtain a firm reinforced joint 75.

The mechanical joining methods shown in FIGS. 27 to 29 can also be applied to either single or double lapings. The process of FIG. 27 utilizes a cut out tongue piece 76 from the lapping 77 which is folded along the lapping 77. In FIG. 28, there is shown the use of rivets 78 to form a tightly sealed lapping 79 and in FIG. 29, fasteners 80 are used to join the lapping 81.

EXAMPLE

The continuous case was made by the two stage forming means with seam welding as described in detail in the embodiment of FIGS. 1–14. A low carbon cold rolled steel strip having a thickness of 0.6 to 1.0 mm. was employed as the strip material for the continuous case. The main forming roll of the forming means was 150 mm. in diameter. The width of each lapping at the four corners of the continuous case was 15 mm. The lapping was continuously welded by a pair of rotary electrodes having a diameter of 200 mm. The continuous case was cooled by water applied at the rate of about 0.4 ton per square meter of surface area every minutes at a pressure of 4.5 kilograms per square centimeter. The molten steel was an ordinary carbon steel with a chemical analysis of: 0.13–0.17% carbon, 0.22–0.36% silicon, 0.63–1.22% manganese, 0.010–0.018% phosphorus, 0.011–0.024% sulfur, and the balance iron. The temperature of the molten steel was about 1500°C.

The following table shows the withdrawal speed of the steel strand and the casting productivity under the above conditions when the thickness of the steel strip and the continuous case cross section are varied.

<table>
<thead>
<tr>
<th>Example</th>
<th>Continuous case thickness, mm.</th>
<th>Withdrawal speed, in./min.</th>
<th>Productivity, lb./hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>250×200</td>
<td>1.0</td>
<td>2.2</td>
</tr>
<tr>
<td>II</td>
<td>250×200</td>
<td>0.6</td>
<td>1.9</td>
</tr>
<tr>
<td>III</td>
<td>250×250</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>IV</td>
<td>250×300</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

It has been proved that a high casting productivity and an excellent advantage are obtained by the present invention. In addition, it has been found that the steel strand thus produced in accordance with the present invention has a surface quality at least as good as the product produced by conventional casting processes.

In the foregoing example, a continuous casting product from an ordinary carbon steel was described; however, it will be appreciated that all grades of steel used in continuous casting processes can readily be used in the present invention.

Thus, there has been provided an efficient and economical continuous casting process and apparatus which are well adapted to attain the ends and objects set forth in the specification, and which may be readily modified in several ways so as to best adapt the process or apparatus to the conditions of the particular casting operation.

It will be understood that variations of the process as outlined above and of the apparatus for carrying out the process may be made within the spirit and scope of the invention hereinafter set forth and hereinafter claimed.

What is claimed is:

1. A process for the continuous casting of steel comprising:
   supplying a plurality of steel strips at a position adjacent a supply vessel containing molten steel,
   moving said strips in a vertical downward direction to make an open-ended tubular hollow body,
   forming the edges of said strips into protruded lapings at each corner of said body,
   joining said lapings of said body to make a sealed continuous case,
   pouring said molten steel into said case,
   cooling and supporting said case to solidify said molten steel and to prevent bulging of said case,
   and withdrawing said cast steel downwardly at a speed of a value of V given by the following formula:

\[
V = \frac{6.0 \times 10^4}{L} \left( \frac{0.72}{m} + 0.55 \right)
\]

where

\[
m = \text{sheet thickness of the steel strip, cm.},
L = \text{length of the longest side of the continuous case in cross section, cm.},
V = \text{withdrawal speed of cast steel, cm./sec.}
\]

2. Apparatus for the continuous casting of steel comprising:
   a plurality of steel strips of indefinite length,
   a deflecting roller associated with each steel strip for moving said steel strip in a vertical downward direction to make an open-ended polygonal tubular hollow body,
   at least some of said deflector rolls being provided with frusto-conical end portions, an auxiliary forming roll of frusto-conical configuration cooperating with a frusto-conical end portion of said deflecting rolls to provide flanged edge portions on at least some of said steel strips,
   means for introducing the flanged edges of some of said strips in lapped relationship with the edge portions of the remaining steel strips, said means being adap-
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9  for bending said flanged portions in complementary configuration with the edge portions of said remaining steel strips,
means for joining said lapped edge portions to make a sealed continuous case,
means for supplying molten steel into said case, a plurality of vertically spaced roller supports abutting and extending the width of a respective steel strip of said case,
a conduit pipe provided with a plurality of spray nozzles located below and adjacent each of said roller supports and extending axially the length thereof for discharging a coolant over the surface of said joined steel strips, and
means for withdrawing said cast steel downwardly.

3. The structure as recited in claim 2, wherein said auxiliary forming rolls comprise deflecting rolls for said remaining said steel strips, each of said forming rolls being provided with frusto-conical edge portions cooperating with the edge portions of adjacent deflector rolls to form lapped, adjacent flanged edge portions on adjacent steel strips.

4. The structure as recited in claim 2, wherein said joining means includes welding apparatus provided with rotary electrodes engaging opposed surfaces of the lapped edge portions.

5. The structure as recited in claim 2, and further including:
a forming guide assembly including means cooperating with said deflecting rollers for insuring passage of the steel strips over the deflecting rollers and additional means inerterable in the polygonal enclosure for providing a guard for the splashing of molten metal introduced into the polygonal enclosure.

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