Aug. 20, 1968 J. D. GRICOL 3,397,733

METHOD FOR REMOVAL OF GAS FROM MOLTEN METAL DURING CONTINUOUS CASTING

Filed Dec. 13, 1965

FIG. 1

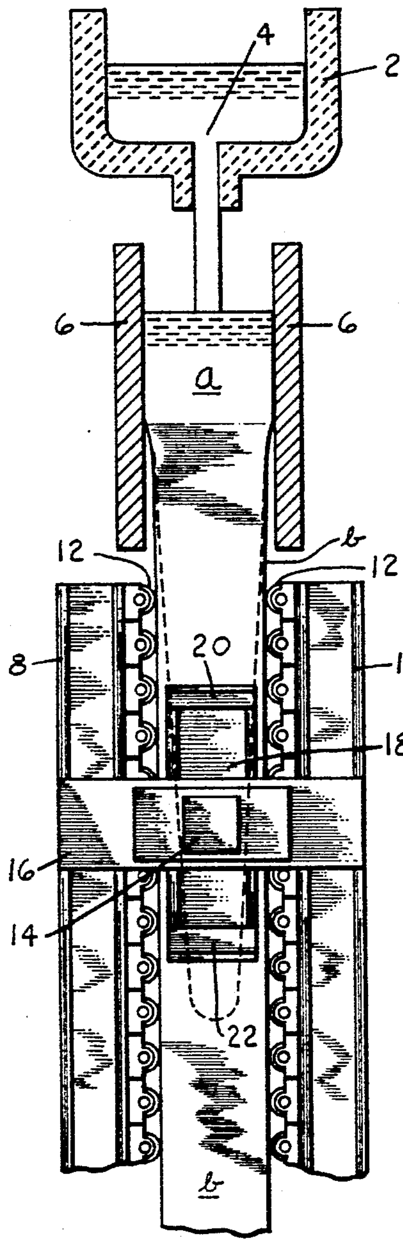
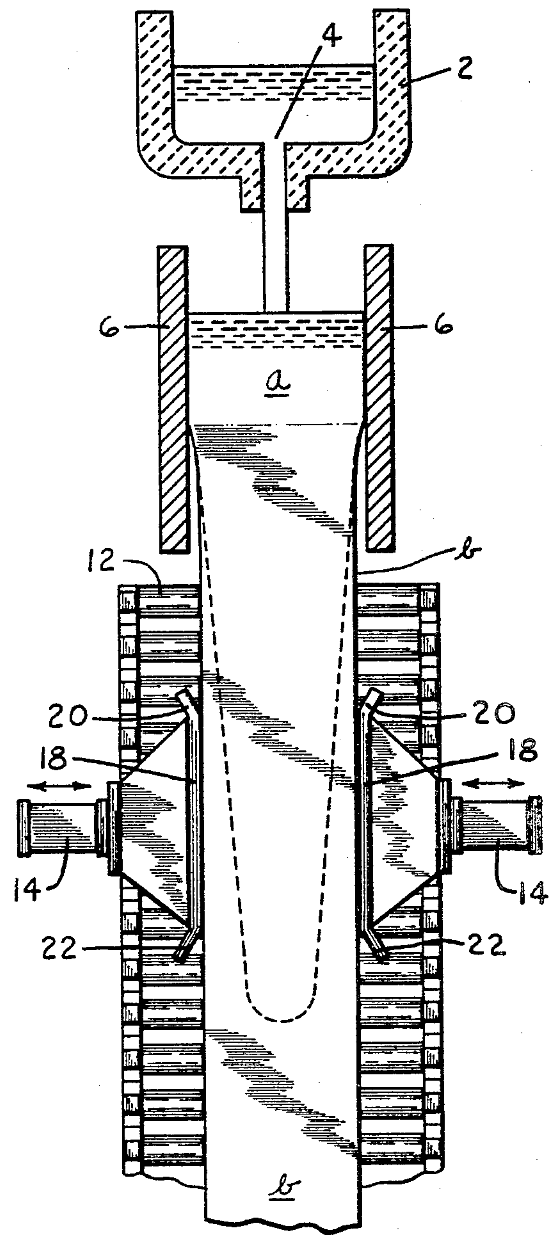


FIG. 2



United States Patent Office

3,397,733

Patented Aug. 20, 1968

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3,397,733

METHOD FOR REMOVAL OF GAS FROM MOLTEN METAL DURING CONTINUOUS CASTING

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Filed Dec. 13, 1965, Ser. No. 513,244
1 Claim. (Cl. 164—71)

ABSTRACT OF THE DISCLOSURE

Vibrations are applied to a slab of cast metal emerging from a continuous-casting mold at a position along the slab at which the interior of the slab is still molten. The frequency of the vibrations are adjusted to be in resonance with the portion of solidified metal skin around the slab between the position at which the vibrations are applied and the point at which the skin is formed in the mold; the amplitude of the vibrations are adjusted to agitate the surface of the molten metal in the mold.

This invention relates to the continuous casting of steel and, more particularly, to the continous casting of rimming steel.

In continuous casting of steel, molten steel is poured into are upper end of a mold open at its bottom. The mold is cooled with a liquid, such as water, circulated in the mold walls. The molten metal in contact with the mold wall is cooled or chilled and solidifies. This solidified metal forms a skin or sheath around the molten metal.

The cast metal leaves the bottom of the mold in a continuous ribbon or cast. The ultimate length of the continuous cast, of course, depends upon the amount of molten metal poured into the top, or tundish, of the mold. Casts of indefinite length can thus be continuously cast.

The length of the mold employed in continuous casting of steel is relatively short. As the molten metal moves through the mold the metal in contact with the mold wall is cooled and solidifies. At the point where the cast slab leaves the mold there is only a relatively thin skin or sheath of solid metal at the exterior of the slab. The remainder of the metal in the slab is molten and is contained in the slab by the skin of solid metal. As the slab moves away from the bottom of the mold the molten metal continues to cool and solidify, from the exterior of the slab inwardly, increasing the thickness of the skin or sheath until, finally the entire cast slab is solid. The point where complete solidification of the slab occurs is at a substantial distance below the bottom of the mold, as much as thirty-five feet, or more, from the mold bottom in some operations. As the slab emerges from the mold, the slab is supported by rollers engaging the slab from its opposite sides. Some of these rollers are driven and control the speed of the slab.

The melt for continuous casting of rimming steel is prepared at a temperature of about 2950° to 3060° F. The melt is poured into a ladle and from the ladle into the tundish. From the tundish the molten metal is delivered to the continuous casting mold at a temperature of about 2800° to 2875° F.

To obtain the desired rimming action, a regulated amount of uncombined oxygen is left in the molten metal at the time of pouring in the continuous casting of rimming steel. This uncombined oxygen, as the metal solidifies, forms gas in the molten metal. This gas agitates the molten metal, causing the metal to circulate in a pattern. This circulation produces the desired rimming action. It is, of course, desirable that this gas, as it forms in the molten metal, move to the top of the molten metal and escape. Any gas present in the molten metal at the time the metal solidifies is trapped and forms undesirable voids or occlusions in the slab. These voids or occlusions, when they occur, result in flaws and defects when the continuously cast slab is later rolled.

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A substantial portion of the cooling and solidification of the metal in continuous casting occurs below the mold as the cast slab moves away from the mold bottom. The uncombined oxygen still in solution in the molten metal is carried along with the molten metal in the slab until the molten metal is cooled. Thus, at a point in the cast substantially distant from the point where the molten metal is poured into the mold, gas bubbles are still forming.

One of the objects of the instant invention is to provide an improved method for continuous casting of rimming steel.

A further object is to provide apparatus for carrying out such method.

A further object is to provide such a method and apparatus wherein dissolved oxygen which, when it reacts to form a gas, will escape from the cast.

Still a further object is to provide continuous castings of rimming steel which can be rolled into relatively thin sheets without flaws or defects on the surfaces of the sheets.

These and other objects will be more apparent from the following description and attached drawings in which:

FIG. 1 illustrates schematically apparatus of the invention for continuously casting steel, viewed from one edge of the slab being cast; and

FIG. 2 is a view similar to FIG. 1 but viewed from one side of the slab with parts of the apparatus omitted.

Many attempts have heretofore been made to apply vibratory forces to continuous casting operations. For the most part, these prior attempts have involved vibration of the mold or the slab after the metal in the slab is solidified. Such prior attempts employed rugged, expensive equipment, required specially designed molds and had many disadvantages. In addition, they were not effective in removing gas occlusions and voids in the continuously cast slab.

In the instant invention, vibration is applied to the cast slab while a substantial portion of the slab is molten. The shell of solid metal around the molten metal is vibrated so that the tapered walls of solid metal agitate the molten metal within the slab. The agitation causes the gases to separate from the solidfying surface, move upward through the molten metal in the slab center, and escape. In addition, the vibration agitates the molten metal in the mold, causes the molten metal to move in a pattern and improves the rimming action.

In carrying out the invention, vibrators are positioned at the opposite edges of the slab at a point below the mold where the center of the slab is still molten. These vibrators are in contact with the opposite edges of the slab and impart vibration to the solid metal around the exterior of the slab. From the point where this vibration force is applied, upward of the slub and into the mold area, the thickness of the solid metal wall around the molten metal progressively decreases. This progressive decrease in solid metal thickness has been discovered, in the instant invention, to result in a tuning action. The upwardly extending arms of solid metal act as tuning forks, or a tuned horn, with the center filled with liquid molten metal.

The vibration input, at the point where the vibratory force is applied to the slab, is relatively low. However, the progressive decrease in thickness of the solid metal from the input point to the point where the molten metal is initially cooled and the skin or shell of solid metal begins to form, results in an increase in vibration amplitude from the point of input to the point in the mold where the walls of solid metal initially form. This increase in amplitude correspondingly increases the agitation of the molten metal. Thus, gas bubbles are released from the solidifying surface and move upwardly through the molten metal to escape into the atmosphere.

Referring now to the attached drawings where the apparatus of the instant invention is schematically illustrated on a conventional continuous steel casting machine, the apparatus includes tundish **2**, open at its top and having a nozzle **4** at its bottom. A mold **6** is disposed below tundish **2**, in position to receive molten metal from nozzle **4**. Mold **6** is reciprocated, in conventional manner, parallel to the direction of movement of the cast slab by conventional means not shown. In its downward travel, mold **6** is driven at a speed slightly faster than that of the cast being continuously formed and is moved upward at a higher speed, all in accordance with conventional continuous casting of steel procedures.

Mold **6** is open at its top and bottom. Vertical beams **8, 10** are disposed in parallel position below the open bottom of mold **6**. Each beam **8, 10** is provided with a plurality of rollers **12**, the rollers being relatively closely spaced vertically along the beams on the facing sides of beams **8, 10**.

Vibrator **14** is mounted on support **16** intermediate beams **8, 10**. A shoe **18** having, at its opposite vertical ends, outwardly turned portions **20, 22**, is connected to, and driven by, vibrator **14**. Preferably, two vibrators are employed, one at either edge of the cast slab.

In operation, molten metal is poured from a source, not shown, into the upper open end of tundish **2**. The molten metal flows through nozzle **4** into the open upper end of mold **6**. The flow of metal through nozzle **4** is regulated, in known manner, to maintain the level of molten metal in the mold cavity at the required height.

Liquid, such as water, is circulated in the walls of mold **6** to cool the walls. As the molten metal passes through mold **6**, the metal in contact with the walls is cooled and the metal solidifies, forming a shell or sheath of solid metal around the molten metal in the center of the mold cavity. Thus, while in the mold cavity, solid metal *b* commences to form as a shell or sheath around molten metal *a*.

When the cast slab emerges from the bottom of the mold **6**, the shell or sheath of solid metal *b* is relatively thin. As the slab moves away from the bottom of mold **6**, cooling continues. This cooling may be supplemented by spraying a liquid, such as water, against the slab as the continuously forming slab travels away from the bottom of mold **6**. Cooling progresses from the exterior of the slab inwardly. Additional molten metal *a* solidifies on the interior of the shell or sheath of solid metal *b*, thickening the shell or sheath of solid metal until, finally, at a substantial distance below the mold, all of the metal in the cast is solidified.

The cast, as it emerges from the mold, comes into contact with rollers **12** carried on beams **8, 10**. Rollers **12** maintain the slab in alignment and support the slab during cooling. These rollers may be idle rollers or may be driven. Preferably, some of the rollers are idle and others are driven. The drive on the driven rollers regulates the speed at which the continuous cast is formed.

Vibrators **14**, through shoes **18**, vibrate the cast, from its opposite edges, in the direction of the arrows in FIG. 2. The vibrators are located on the apparatus below the mold bottom where the wall of solid metal in the cast is relatively thick but the center portion of the cast slab is of molten metal. The vibratory force applied to the cast, through the solid metal *b*, agitates the molten metal *a* in the cast and causes gas bubbles, as they form on solidification of the metal, to separate from the solidifying surface and move upwardly through the molten metal in a direction opposite to the travel of the continuous cast.

The vibration input may be tuned to the resonant frequency of the solid metal *b* in the walls of the solid metal shell above the vibrators. The amplitude and frequency required for resonance will, of course, vary with the size of the cast, the amount of cooling and the like, but can be readily determined by observing the activity of the molten metal in the mold. The amplitude and frequency of the vibrators are adjusted to bring the surface of the molten metal in the mold to the desired agitation. The amplitude of vibration of the solid metal shell increases from the point of vibration input as the thickness of the solid metal decreases. Thus the agitation imparted to molten metal *a* by vibration of solid metal *b* increases from the vibration input point upwardly into the mold cavity. By regulating the vibration input, agitation of the molten metal in the mold can be controlled. This control of the agitation permits the molten metal to form a rim of solid metal around the exterior of the continuously cast slab and facilitate the movement of impurities away from the surfaces of the slab in addition to decreasing voids and occlusions near the slab surfaces.

The capacity of the vibrator will, of course, depend on the size of the steel slab to be continuously cast and, preferably, should be of a type that can be regulated. An air-powered vibrator having a capacity of 100,000 pounds thrust and frequency up to 3,000 cycles/min. has been found particularly suited for the production of continuously cast rimming steel slabs having a thickness of ten inches and a width of fifty-two inches.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. In a method for continuously casting a slab of rimming steel wherein molten steel is poured in one end of an open-ended continuous-casting mold that is cooled to form a shell of solidified metal around the metal therein, a continuous slab of the metal having a solidified shell and a still molten interior is withdrawn from the other end of the mold, and the slab issuing from the mold is thereafter continuously cooled to solidify the slab all the way through, the improvement comprising: removing gas from the molten metal in said slab by applying a vibratory force directly to the side of the slab after it emerges from the mold and at a position along the slab at which the interior of the slab is still molten with said molten interior extending up into the molten metal in the mold; adjusting the frequency of the vibratory force to apply it at the resonant frequency of the skin of solidified metal which is between said location and the point of formation of the skin in the mold; and adjusting the amplitude of the vibratory force to a level sufficient to agitate the surface of the molten metal in the mold.

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