United States Patent [19] [11] **3,840,062**
Kenney [45] **Oct. 8, 1974**

[54] **CONTINUOUS STEEL CASTING METHOD**

[76] Inventor: **Malachi P. Kenney**, Shepherd Hill Rd., East Aurora, N.Y. 14052

[22] Filed: **July 18, 1968**

[21] Appl. No.: **745,728**

[52] **U.S. Cl.** **164/66,** 75/96, 164/82
[51] **Int. Cl.** .. **B22d 21/02,** B22d 23/00, B22d 11/00
[58] **Field of Search** 164/66, 57, 275, 273, 281, 164/259, 266, 83, 82

[56] **References Cited**

UNITED STATES PATENTS

2,889,596	6/1959	Savage et al.	164/283
2,983,973	5/1961	Parlanti	164/66 X
2,997,384	8/1961	Feichtinger	164/66 X
3,094,424	6/1963	Ratcliffe	164/281 UX
3,281,903	11/1966	Ross	164/66
3,392,009	7/1968	Holmes et al.	164/66 X
3,402,757	9/1968	Halliday	164/66
3,459,537	8/1969	Hornak	75/49
3,465,811	9/1969	De Castelet	164/281
3,467,167	9/1969	Mahin	164/66 X

FOREIGN PATENTS OR APPLICATIONS

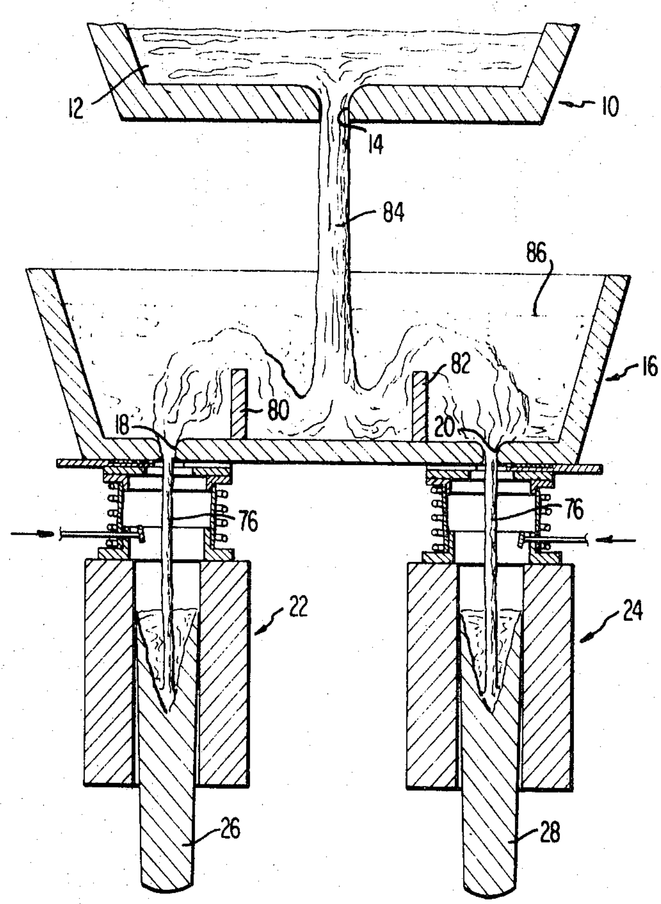
411,245	4/1966	Switzerland	164/66
1,395,648	3/1965	France	164/66

Primary Examiner—J. Spencer Overholser
Assistant Examiner—Vernon K. Rising
Attorney, Agent, or Firm—Bean & Bean

[57] **ABSTRACT**

Oxide inclusions in continuously cast steel are constrained to be well dispersed and predominantly of very small size by controlling the environment and nature of the tundish-to-mold stream continuously to exclude and remove oxygen and gasses containing oxygen so as to inhibit oxide formation except as is incidental to the cooling and freezing of the metal in the mold itself.

1 Claim, 4 Drawing Figures



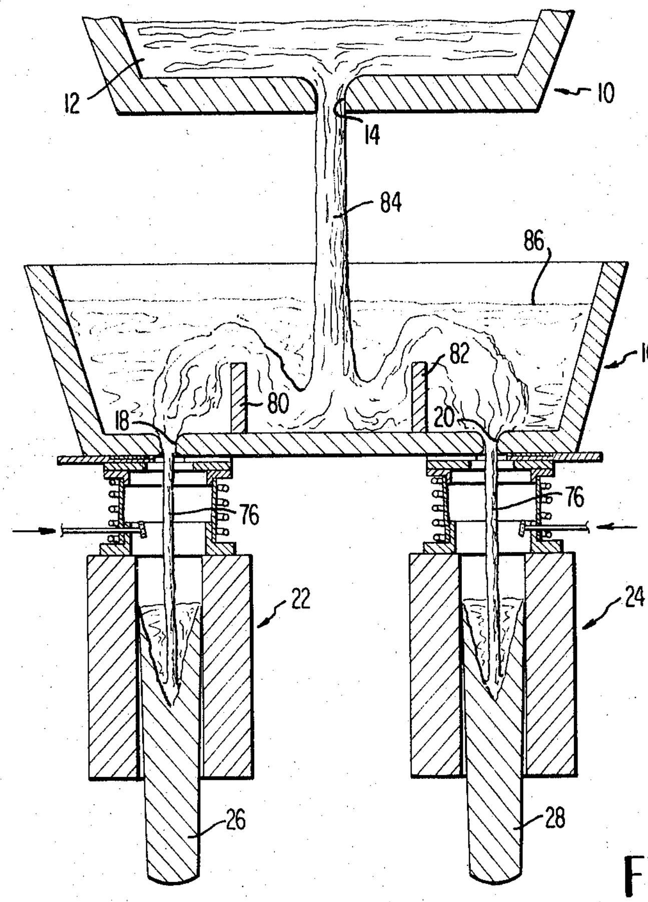


FIG. 1

FIG. 4

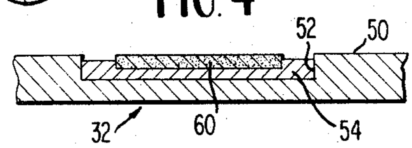
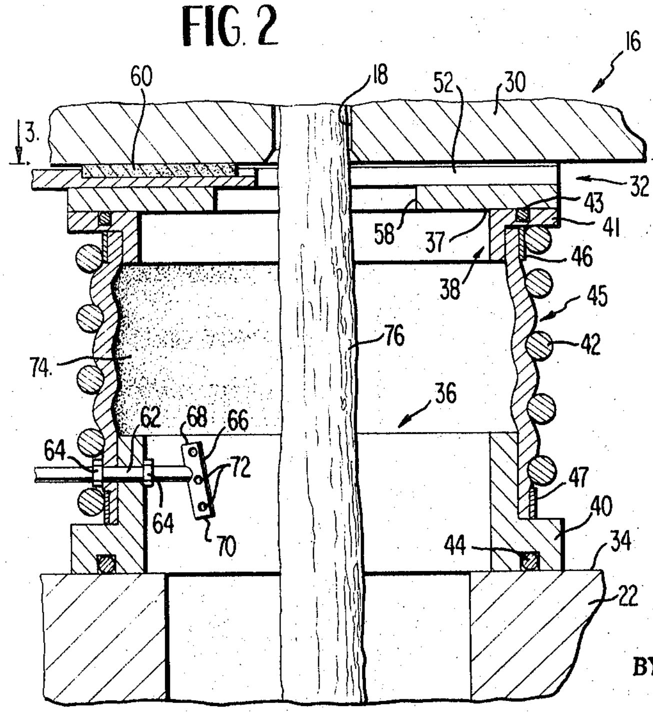


FIG. 2



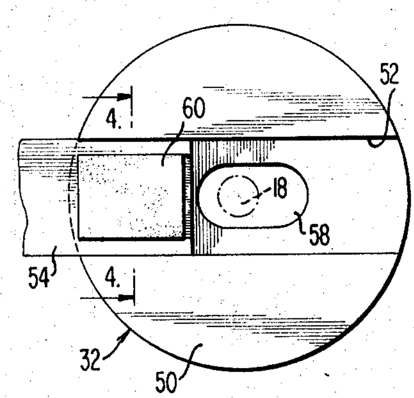


FIG. 3

INVENTORS
MALACHI P. KENNEY

BY

Bean & Bean
ATTORNEYS

CONTINUOUS STEEL CASTING METHOD

BACKGROUND OF THE INVENTION

It is well recognized that inability to control the size of nonmetallic (oxide) inclusions incidental to the production of steel by continuous casting methods has prohibited the continuous caster from supplying steel for high quality application such as for bearings, aircraft parts or the like.

Although the formation of these inclusions is known to be due to the presence of oxygen in the molten steel, careful control of oxygen content, such as is successful in producing high quality reduced ingot steel, is not adequate in producing high quality continuously cast steel. The reason for this is that although as compared with ingot cast steels, the size of nonmetallic inclusions in continuously cast steel actually may be smaller initially, owing to the fact that ingots are of relatively large cross section while continuous cast billets are of relatively small cross section, the former undergo a much greater reduction in cross section during subsequent processing. Consequently, the nonmetallic inclusions in an ingot product are elongated, broken up and greatly reduced in cross section so that ultimately they may be much smaller in size than in a comparable product made from a continuously cast billet. For example, a typical ingot having approximately 600 square inches of cross section when reduced to a 1 inch square bar must undergo about 40 times the reduction required to reduce a typical 4 inch square continuously cast billet to the same size.

Thus, the attainment of low oxygen content in continuously cast steel, which compares with that leading to high quality products from reduced ingot steel, is unsuccessful in producing what are ordinarily considered to be high quality continuously cast steel products. Unfortunately, the obvious solution of still further reducing the oxygen content is not one which at present appears to be practicably attainable. That is to say, an ideal situation with regard to either continuous cast or reduced ingot cast steels would be to reduce the oxygen content to zero, but this ideal is at present, far from attainable.

The methods used to control the oxygen content of continuously cast steel include the usual chemical additions to the furnace and the ladle (i.e., the addition of silicon and/or aluminum to the molten steel) and the use of means to prevent steel-air contact, particularly in the teeming stream from ladle to tundish and in the stream between tundish and mold. The theory underlying these proposals is that prevention of steel-air contact will exclude oxygen pick-up from the atmosphere and allow the ordinary chemical methods of deoxidation to reduce the oxygen content of the steel to such a low value as minimizes the presence of nonmetallic inclusions.

Although some improvement is obtained by these methods, the results are far from satisfactory inasmuch as the presence of substantial quantity of large sized nonmetallic inclusions remains a problem.

BRIEF SUMMARY OF THE INVENTION

This invention is directed to method and apparatus for continuously casting steel, in which method the formation of oxides due to the inevitable presence of oxygen in solution is controlled so that the oxides predominately are present in the cast steel in the form of widely dispersed inclusions of small size.

The process involves the use of a tundish into which the molten steel is teemed from a suitable ladle, whereafter the molten steel is directed in one or more streams to a conventional continuous casting mold or molds. Chemical deoxidation of the steel is effected by ladle addition and the oxides formed by such chemical deoxidation in the tundish, as well as oxides carried over from the ladle largely are separated out in the form of slag floating on the surface of the molten steel in the tundish.

The tundish-to-mold stream is protected by a gaseous envelope to:

a. prevent the introduction of exogenous oxygen,

b. remove oxygen and oxygen compounds from the molten steel stream, and

c. inhibit the formation of oxides in the tundish-to-mold stream and limit the formation of oxides substantially to that which is incidental to the freezing of the metal in the mold.

It has been found that if the above effects are carried out, substantially all of the oxide inclusions in the continuously cast steel will be less than about 20 microns in size and well dispersed whereby the quality of the steel materially is improved.

Specifically, these effects are accomplished by enclosing the tundish-to-mold stream within a flexible, porous sleeve, into which high purity argon gas is introduced under pressure sufficient to cause a continuous flow of the inert gas which constantly flushes the inert atmosphere and thereby removes oxygen, carbon monoxide and gaseous compounds which may contain oxygen from the inert atmosphere, whereby to stimulate and continuously maintain the atmosphere in condition to favor the diffusion of oxygen and gaseous compounds containing oxygen into such atmosphere.

Although the exact mechanism by which the present invention operates is not as yet known, it is believed that the mechanism involves diffusion of oxygen in solution in the molten steel into the inert atmosphere, reduction of oxides already formed, and the formation of carbon monoxide which diffuses into the inert atmosphere; and that these and possibly other gaseous diffusions distinctly inhibit oxide formation except as is incidental to the cooling and freezing of the metal in the mold. The cooling and freezing of the metal in the mold takes place rather rapidly and this is believed to lead almost exclusively to the formation of oxides which are well dispersed and of the small size heretofore mentioned.

I have found that large size, quality degrading nonmetallic inclusions in continuously cast steel may be largely eliminated not so much by a consideration of the oxygen content of the steel itself, although this is of importance, but mainly by continuously subjecting the tundish-to-mold stream or streams to an atmosphere conducive not only to the exclusion of oxygen contact with the steel, but also to removal of oxygen or oxygen-containing gas from the steel at this point.

Preferably, I effect this deoxidation and oxygen exclusion of the tundish-to-mold stream by enclosing the stream in a high purity argon atmosphere while continuously changing the atmosphere so that at all times the argon possesses substantially zero partial pressure of oxygen and oxygen-containing gas. Under these conditions, the oxides which do form in the solidifying steel, due to precipitation of oxygen therefrom as the steel cools and freezes, are present as widely dispersed nonmetallic inclusions which are so small as do not materially affect the quality of the steel.

It is important to note that whereas it is of interest to maintain the oxygen content of the steel to a value below about 100 PPM in the present process, this value lies within normal ranges for continuously cast steel. To illustrate, conventionally cast continuous steel exhibits an oxygen content within the range of about 60 to about 160 PPM and do contain substantial quantity of large size, quality-degrading nonmetallic inclusions whereas with the present process the oxygen content of the continuously cast steel ranges only slightly lower (between about 40 to about 90 PPM) but with the substantial absence of large size nonmetallic inclusions, the oxides instead being present predominantly as well dispersed inclusions of sizes less than about 20 microns.

BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWING

FIG. **1** is a vertical section taken through the apparatus for practicing the continuous casting process according to the present invention;

FIG. **2** is an enlarged section taken through the shroud which encloses the tundish-to-mold stream;

FIG. **3** is a section on reduced scale taken along the plane of section line **3—3** in FIG. **2** and showing the cutoff valve device; and

FIG. **4** is an enlarged transverse section taken along the plane of section line **4—4** in FIG. **3.**

BRIEF DESCRIPTION OF THE INVENTION

With regard to FIG. **1,** the reference character **10** indicates in general a ladle, only the lower portion of which is shown in FIG. **1** and which will be understood to contain molten steel **12** obtained by furnace processing. The ladle is provided with a suitable nozzle or orifice **14** in its bottom and a conventional stopper rod (not shown) is utilized in conjunction therewith to control the flow of steel from the ladle **10** to the underlying tundish **16.** The tundish is provided with a pair of nozzle or orifice portions **18** and **20** for delivering the molten steel to the reciprocatory open ended molds **22** and **24.** It will be understood that the molds **22** and **24** are of entirely conventional construction as used in the continuous casting industry and are provided with the usual mechanism (not shown) for effecting vertical reciprocatory motion of these molds continuously to follow and then strip from the billets **26** and **28** formed.

As can be seen more clearly in FIG. **2,** the bottom wall **30** of the tundish is provided under each nozzle **18** and **20** with a valve plate assembly indicated generally by the reference character **32** and the upper faces **34** of the molds **22** and **24** form seats for the collars **36.** The lower face **37** of each valve plate assembly **32** forms a seat for the upper collar **38,** the two collars **36** and **38** being provided with flanges **40** and **41** which form seats for and are urged apart by the compression spring **42** and interposed between the collars and their respective seating surfaces **34** and **37** are packing or sealing rings **43** and **44** received in suitable grooves in the collars and adapted, under the action of the spring **42,** to effect seals at these points.

Enclosed within each spring **42** is a porous sleeve **45** having its opposite ends clamped upon the collars **38** and **36** by suitable bands **46** and **47,** it being understood that the sleeves **45** are of sufficient length to accommodate for the maximum extension between the molds **22** and **24** and the tundish **16.**

The valve plate assembly **32,** as may be seen more clearly in FIGS. **3** and **4** includes a main body portion **50** provided in its upper surface with a slot **52** receiving the cutoff plate member **54.** The main body portion **50** of the valve may be of circular profile presenting a relatively large central opening **58** in register with the tundish nozzle **18** whereas the plate **54** is adapted to be moved between covering and uncovering relation to the tundish nozzle **18.** As may be seen in FIG. **4,** the plate **54** is provided with a graphite insert **60** which bears against the bottom surface of the tundish, the insert being provided to prevent welding of the plate **54** to the tundish when the plate is moved into covering relation to the tundish nozzle.

Each of the collars **36** is provided with inert gas inlet means which, as can be seen in FIG. **2,** may comprise a tube **62** suitably anchored as by the nuts **64** and terminating in a cross tube portion **66** which is closed at its opposite ends **68** and **70** and provided in its lateral side faces with openings **72** to admit the inert gas into the enclosure **74** formed by the porous sleeve **45.** Each sleeve **45** is formed of suitable material such as a woven asbestos material having sufficient refractory properties to withstand the heat of its environment and yet having suitable porosity to allow leakage of the inert gas therethrough. The sleeve **45** is of course flexible to accommodate for the vertical reciprocatory motion of the molds **22** and **24.**

The inert gas, preferably high purity argon, is introduced into the enclosures **74** under sufficient pressure to assure a leakage or bleed-off rate of the inert gas from the enclosures **74** which is effective to change and flush the inert gas atmospheres in the enclosures **74** so as to maintain the atmosphere substantially free of oxygen or oxygen-containing gas whereby to favor deoxidation of the tundish-to-mold stream **76.** Preferably, the bleed rate of the inert gas is in the order of 23.44 cubic feet per minute while casting the two, four inch square, billets **26** and **28** (in the order of 48 cubic feet per ton of steel) and typically an internal pressure within each enclosure **74** of about one and one-half pounds per square inch gauge is sufficient to assure such leakage rates. A suitable pressure regulating valve and pressure gauge, not shown, are provided to allow the operator to control the bleed rate.

The tundish construction is of entirely conventional nature except for the provision of a pair of dams **80** and **82** upstanding from the bottom walls and extending between the opposite side walls of the tundish. These dams are placed so as to trap the ladle-to-tundish stream **84** therebetween and cause the incoming molten metal to flow upwardly toward the surface **86** of the tundish reservoir before passing downwardly to the nozzles **18** and **20.** The surface **86** is of course maintained at a level higher than the dams and means may be provided, not shown, automatically to control the ladle-to-tundish flow for maintaining a fixed metallostatic head in the tundish.

The dams **80** and **82** are provided to enhance the natural separating effect of the tundish by aiding nonmetallic inclusions in the molten steel in finding their way to the surface **86** whereat they may remain as slag, thereby preventing carry-over into the molds.

Calcium and/or silicon are used in the ladle as a deoxidizing agent and the agent preferably is used in the amount of about **5** pounds per ton of steel, sufficient to establish an oxygen content in the tundish of about 60–190 PPM. The dams **80** and **82** help in assuring that the oxides formed by the aforementioned deoxidizing agents find their way to and remain as slag on the surface **86** of the tundish reservoir so that slag carry-over is also minimized. Typically, the depth of the tundish reservoir may be about 17 inches using two 11/16 inch diameter nozzles **18** and **20** to form 4 inch square billets **26** and **28.** The tundish-to-mold streams **76** are about 15 inches in length and the casting time for a 22 ton heat is approximately 45 minutes.

With the above conditions prevailing, using high purity argon gas supplied from a suitable source at a pressure of about 1.5 PSIG and at a through-rate of about 48 cubic feet per ton of steel, the steel will be characterized by the substantial absence of nonmetallic inclusions larger than about **20** microns and may be produced on a quantity and repetitive basis. The nonmetallic inclusions which are present in the steel are mainly in the form of extremely fine and widely dispersed oxides such as manganese, silicon, aluminum and calcium oxides.

Five test heats, each of approximately 22 tons capacity, were cast of AISI C-1050 steel, one strand or billet of which was subjected to protection and deoxidation of its tundish-to-mold stream according to this invention while, the stream forming the other strand was exposed to air. A comparison of the results illustrating the percent reduction between the control strands and the strands cast according to this invention is as follows:

		Percent Reduction
Oxygen analysis	(average)	33%
NMI count	(average)	74%
NMI size	(average)	78%

From the above, it becomes clear that the factor of oxygen content reduction in the billet is not the only factor involved inasmuch as the reduction in oxide or nonmetallic inclusion count and size is far in excess of the reduction in oxygen content. Moreover, as noted earlier, the oxygen content of the steel obtained by the present invention overlaps the range obtained by conventional processing, the former as noted being about **40-90** PPM with the latter being about 60–160 PPM.

Rather, the presence substantially only of oxide inclusions in the present invention which are extremely fine (less than about 20 microns) and widely dispersed appears to be due at least in large part to the combined effect of protection and deoxidation of the tundish-to-mold stream. Tests conducted with a protective atmosphere around the tundish-to-mold stream but without provision for deoxidation at this point, although showing reduction in nonmetallic inclusions as compared with an unprotected stream, do not compare favorably with the results produced by this invention. A protective atmosphere in the absence of the deoxidizing effect may be expected to produce only about one-sixth to about one-third the effect produced by this invention insofar as quantity of large size nonmetallic inclusions is concerned.

From the above, it will be clear that this invention involves simultaneously the protection and deoxidation of the tundish-to-mold stream by enclosing the same in an inert atmosphere and changing the atmosphere at a rate continuously to effect deoxidation of the stream. As has been mentioned, the continuous changing of the inert atmosphere is believed to so favor the diffusion of oxygen and oxygen containing gas from the stream to the atmosphere as inhibits the formation of oxides in the steel except as is incidental to the cooling and freezing of the steel in the mold, whereat they may form as well dispersed and very small inclusions in the steel. In particular, it appears that any inert atmosphere having substantially zero pressure of oxygen and carbon monoxide will, if changed at a rate to retain such substantially zero partial pressures, so favors the deoxidation of the steel as to accomplish the desired result. Accordingly, other and different inert atmospheres, rather than argon as specifically disclosed, may be used.

What is claimed is:

1. The method of continuously casting a high quality steel characterized by minimization of nonmetallic inclusions of a size greater than about **20** microns, which comprises the steps of:

a. making a heat of molten steel and pouring it into a ladle;

b. chemically deoxidizing the molten steel in the ladle to establish an oxygen content in the molten steel which is in the range of about 60–190 ppm;

c. teeming the molten steel from the ladle into a tundish while simultaneously streaming the molten steel from the bottom of the tundish into a continuous casting mold and controlling the flow of molten steel in the tundish to direct the molten steel coming into the tundish back toward the surface of the molten steel before passing to the continuous casting mold;

d. passing the tundish-to-mold stream through a flexible, porous sleeve which is sealed at opposite ends to the tundish and the mold whereby to form a protective enclosure around said tundish-to-mold stream;

e. introducing a high purity inert gas into said protective enclosure under sufficient pressure to cause a continuous flow of such gas into such enclosure and then outwardly thereof through said porous sleeve; and

f. continuously maintaining the flow of gas of step (e) during casting at a rate sufficient continuously not only to exclude and to remove oxygen and gasses containing oxygen from said enclosure but also to deoxidize the tundish-to-mold stream and thereby constrain nonmetallic inclusions formed in the solidified steel in the mold to be well dispersed and of sizes less than about **20** microns while reducing the oxygen content of step (b) and obtain an oxygen content in the solidified steel which is within the range of about **40** to about **90** parts per million.

* * * * *