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**METHOD OF PRODUCING LOW CARBON,
NON-AGING, DEEP DRAWING STEEL**

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7 Claims. (Cl. 75—59)

This application is a continuation-in-part of Ser. No. 357,285 filed Apr. 3, 1964, now abandoned.

This invention relates to the production of steel wherein an inert gas is used in the final processing steps, and more particularly to a process for producing an open hearth, basic oxygen vessel or electric furnace steel product which is killed but yet is substantially or completely free of metallic deoxidizers. An important part of the invention relates to a specific process for producing low carbon non-aging deep drawing steel.

A killed steel may be defined as one which evolves little or no gases during its solidification.

While not limited thereto, the present invention presents a particularly valuable contribution to the art of producing porosity-free carbon steels by the continuous casting process.

As used herein the term carbon steel refers to ordinary steel which derives its mechanical properties, especially strength and hardness, chiefly from the presence of carbon. Other elements such as manganese, silicon and copper may be present in amounts up to 1.65 percent, 0.6 percent and 0.6 percent respectively. Small quantities of residual elements such as aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium and zirconium may also be present because unavoidably retained from the raw materials. These elements are considered as purely incidental.

Conventionally produced steels which have not been filled are characterized by substantial porosity, resulting from the evolution of carbon monoxide during solidification. This porosity produces defects in the final product which are objectionable in certain circumstances.

To eliminate the porosity and its objectionable effects for many steel uses, oxygen scavenging materials, commonly metallic deoxidizers are added in relatively large quantities with respect to the amount of oxygen present in the metal to react with such oxygen before the carbon therein can react with it to form carbon monoxide.

The resulting oxides formed by the use of such metallic deoxidizers, however, produce non-metallic inclusions, some of which remain in the final product. These inclusions impair the mechanical properties as well as the appearance of such product.

The above-mentioned difficulties are particularly prevalent in the manufacture of low carbon non-aging deep drawing steels, sometimes referred to in the art as aluminum killed deep drawing steels.

Low carbon non-aging deep drawing steel is now widely used in many applications where severe drawing is required for forming a product shape as well as in applications where prolonged storage of the material may be necessary before it is drawn or shaped. At the present time, the automobile industry is probably the largest user of this material. It is believed, however, that the material could find much wider application if a method was provided for producing it more economically in addition to improving its quality.

Low carbon non-aging deep drawing steel may be defined as a steel having the following analysis range (in percent): 0.10 max. C, 0.01 max. Si, 0.20–0.60 Mn, 0.02–0.08 Al, 0.04 max. S, and 0.4 max. P. A typical

analysis of this steel would be as follows: 0.05 C, 0.40 Mn, 0.008 Si, 0.0255 S, 0.008 P and 0.05 Al.

Heretofore this material was made by tapping a molten steel from an open hearth furnace after the carbon content of the melt had been reduced to approximately 0.05% with the sulfur and phosphorus below 0.04%. At this carbon level, the metal leaving the furnace will have an oxygen content on the order of 0.05–0.07 percent. During the tapping, the stream of molten metal usually will pick up about 0.03–0.14% additional oxygen from the surrounding atmosphere. At the same time manganese and aluminum are added to the ladle. The relatively large concentration of oxygen in the metal, however, causes a substantial proportion of the manganese and aluminum additions to be wasted because of their reaction therewith. Approximately 15–40 percent of the manganese and 65–80 percent of the aluminum is lost as a result of such reaction. In other words, it has heretofore been necessary to add considerably more manganese and aluminum to the metal than is actually required for alloying purposes. The excess aluminum and manganese supplied reacts with the dissolved oxygen and produces a substantial amount of non-metallic oxides, many of which float out of the steel and become trapped in the slag.

A substantial portion of non-metallic oxides, however, do not float out of the steel but remain in the form of inclusions in the steel. These oxide inclusions are extremely detrimental to the finished product because they often appear on the product surface as defects, known as streaks and slivers. If the defect-containing material were used, for example, as part of an automobile body the defects would show through the thin paint coatings presently used. The oxide inclusions moreover impair the ductility of the product. It has heretofore been necessary to perform extra surface conditioning, e.g., hand scarfing, as well as to take very stringent quality control measures in order to prevent the appearance of the defects in the finished product.

These quality control measures usually result in the rejection of a very substantial proportion of the material produced. The cost of the quality control measures in addition to the loss attributed to defective product substantially increases the cost of the final product.

In the production of carbon steel by continuous casting, the problems created by excess oxygen in the are even more severe than with the more common ingot practice. In such process, carbon steels, free of metallic deoxidizers will often have excessive porosity adjacent the skin of the product, due to the gaseous evolution of carbon monoxide. When the cast product is reheated for rolling, its thin skin will oxidize and scale off, thereby exposing the internal porous surfaces to oxidation. The oxidation of the internal surface of the material will result in serious defects in the finished product.

Attempts to overcome the above-mentioned porosity problem by the use of metallic deoxidizers creates other serious difficulties, which in many cases the prior art has been unable to eliminate or overcome. These difficulties are particularly prevalent and acute when continuously casting production grades of carbon steel. For example, silicon as a metallic deoxidizer, will impair the ductility characteristics of certain products and is therefore unsuitable. Other metallic deoxidizers, such as titanium, zirconium and vanadium, are prohibitive because of their high cost, and because in many cases they do not offer any significant improvement in ductility.

Aluminum would normally be considered as an acceptable killing agent for many grades of steel, but has been found generally unsuitable in continuous casting. The reason for this is that the presence of more than about 0.01 percent aluminum tends to cause clogging of the pouring nozzle in the continuous casting tundish, producing an un-

even and erratic flow therefrom until the nozzle becomes completely clogged.

It is an object of the invention to provide a process for producing steel which may be killed with the use of relatively little or no metallic deoxidizers, and yet is substantially porosity free.

Another object of the invention is to provide a method of producing low carbon non-aging deep drawing steel more economically than it has heretofore been produced.

Still another object of this invention is to provide a method of producing low carbon non-aging deep drawing steel of excellent quality.

A further object is to provide a method of producing a low carbon non-aging deep drawing steel having only a nominal amount of non-metallic inclusions therein.

A still further object is to provide a method of producing a low carbon non-aging deep drawing steel wherein the manganese and aluminum additions in making such product are added in amounts substantially corresponding to the residual quantity thereof required in the product.

Yet another object is to provide a novel method of producing a high quality carbon steel by the continuous casting process.

Still another object is to provide a novel method of producing a killed steel which is substantially free of metallic deoxidizers, by the continuous casting process.

A still further object is to provide a method for producing a completely carbon-killed steel.

Other objects and advantages will be apparent from the ensuing disclosure and claims appended.

According to the main embodiment of the present invention a method is provided for producing a killed steel which is substantially free of metallic deoxidizing elements, which comprises (a) providing a mass of molten steel which is substantially free of oxidizing slag, within the degassing vessel, said mass of steel having been refined to the desired level of metalloids and having a temperature adequate to provide a sufficient degree of fluidity for teeming; (b) introducing a quantity of inert gas below the surface of the steel to promote the reduction of dissolved oxygen by the dissolved carbon therein; (c) concurrently establishing and maintaining an inert atmosphere within the degassing vessel and above the surface of the metal to prevent infiltration of air thereinto; (d) and thereafter pouring the steel into a mold while substantially excluding air from contacting the steel until the mold is filled therewith.

Preferably an inert atmosphere is established and maintained about the tapping stream to prevent contamination thereof by the ambient atmosphere. This may be accomplished by dispensing an inert gas in a uniform non-turbulent manner from the distributor pipe which substantially surrounds the tapping stream. If the tapping stream is not protected by inert gas, it will be necessary to utilize a greater quantity of inert gas in the vessel degassing step in order to remove the additional contaminants.

Preferably the furnace is tapped when the carbon level is 0.02% to 0.05% (2 points to 5 points) higher than the carbon level desired in the final product.

The inert gas may consist of argon, krypton, xenon, helium or neon, and in certain limited applications, nitrogen may also be employed with success.

For purposes of this invention, a slag may be said to be oxidizing if the iron oxide concentration is greater than ten percent. It is preferable, however, that the slags present during the process of this invention contain less than a five percent iron oxide concentration.

According to one embodiment of the invention, an oxygen scavenging material in finely divided form is dispersed over any oxidizing slag remaining with the steel in order to reduce the iron oxide content thereof. This will render such slag substantially non-reactive, as will be described hereinafter.

According to another embodiment of the invention, substantially all of the inert gas required for lowering the

oxygen and carbon levels to the points desired is introduced into the molten steel before any oxidizing slag enters the degassing vessel. When this embodiment is practiced, in cases where it is mechanically feasible from a practical standpoint, it enables the overall process to be carried out without the slag control steps enumerated elsewhere in the specification. In fact, this embodiment is also advantageous when the slag is reactive, since not only can the melt be reduced to the desired levels of oxygen and carbon, but the presence of the reactive slag after the degassing is complete will not result in the steel picking up phosphorus since the oxygen in the slag will tie up the phosphorus, causing it to remain in the slag. According to this embodiment, if the slag is reactive, the flow of inert gas should either be markedly reduced or completely shut off as soon as any slag from the tapping operation enters the degassing vessel. The object in either case is to prevent the deoxidized steel from picking up relatively large quantities of oxygen from the slag, which would be promoted by the inert gas causing a substantial agitation and mixing between the slag and the steel. In some cases, however, it may be possible to continue the inert gas injection at such a low rate that it will facilitate the stirring in of alloying elements without causing the undesired slag-metal reaction.

To more rapidly and efficiently degas the molten steel, it is preferable to introduce a flow of inert gas into the degassing vessel before the steel is tapped thereinto, and to continue the flow thereof during the tapping operation.

We have found the slag practices enumerated hereinbefore to be a critical part of the overall process, and which often is responsible for the difference between failure and success in producing the desired porosity-free product.

The slags from most steelmaking processes which utilize only one slag usually contain substantial quantities of iron oxides, i.e. between 10 and 50 percent. Usually these iron oxides are retained in the slag and are removed with the slag during the tapping operation; little if any oxidation of the steel by such slag occurs, because the slag is not agitated a great deal, but merely floats on the steel.

We have found, however, that such slags become highly reactive with the steel when inert gas is bubbled into the melt. At this point in the process, the iron oxides liberate oxygen to the steel in substantial quantities, which reacts with the residual carbon present therein. The amount of oxygen liberated ordinarily becomes so great in fact, as to make it extremely difficult to obtain the final carbon levels desired.

The turbulent stirring effect of the inert gas leaving the molten steel, causes the iron oxides present in the slag to be transferred into the steel as the slag is brought into more intimate contact with the steel. The iron oxides are thereafter promoted to react with the carbon present in the steel, forming carbon oxide gases which cause further turbulence and mixing as they leave the molten steel.

The transfer of oxygen to the steel, as iron oxide, will continue until the slag is substantially depleted of its iron oxide, or until the injection of inert gas is terminated. As oxygen is being transferred, the formation of carbon oxides in the steel will continue until the steel is depleted of its carbon. Generally, as the amount of iron oxide in the slag is not accurately known, the final carbon content of the product would become unpredictable, if not fully depleted. A further drawback to the above-mentioned conventional slag practice is that it results in a final product of high oxygen content having poor quality. When the steel solidifies the high oxygen content will combine with any metallics present to form substantial quantities of non-metallic inclusions, rendering the product poor in quality due to excessive porosity as well as an undesirable final analysis.

The problems mentioned become even further magnified as the slag is depleted of its oxygen in that such slag can no longer hold other deleterious impurities such as

phosphorus, which then are picked up by the steel. Phosphorus is undesirable because, among other things, it causes severe embrittlement of the product.

These difficulties will be completely avoided by tapping the metal so that it is substantially slag-free when it enters the degassing vessel.

As a further step in our overall process for producing a porosity-free steel, we disperse a finely divided oxygen scavenging material over the surface of any oxidizing slag remaining with the metal after tapping. Examples of suitable oxygen scavenging materials include aluminum shot, ferrosilicon, calcium-silicon as well as various forms of carbon, e.g. crushed graphite. The amount of oxygen scavenging material added should be substantially equal to the stoichiometric amount required to combine with the iron oxides present in the slag. In most instances, the amount of iron oxide present in the slag will have to be estimated, based upon prior heats. For a given steel making practice, the iron oxide content of the slag should remain substantially constant, so that estimates of the iron oxide content of the slag can be reasonably accurate.

The effect of this supplementary slag deoxidizer step is to render any remaining oxidizing slag unreactive with respect to the carbon in the metal. Since little slag is present with the metal at this stage of the process, the amount of phosphorus or other impurities that will be transferred to the metal, due to the deoxidation of the slag, will be insignificant.

While we generally prefer to substantially neutralize the small quantities of slag tapped into the ladle with the steel, this invention also contemplates the alternative method of substantially neutralizing the slag in the furnace, before tapping.

The slag may be said to be substantially neutralized if the iron oxide concentration has been lowered to less than ten percent, although it is preferred that the concentration be reduced to less than five percent.

The temperature at which steel is normally tapped will usually be insufficient to provide the fluidity needed for teeming if there is an intervening period required for degassing the melt with inert gas. In such case, the metal temperature before tapping should be increased by an amount equal to the expected degassing period multiplied by the steady state temperature loss of the steel in the specific ladle utilized.

After taking the necessary steps to either remove substantially all of the oxidizing slag from the metal or to substantially neutralize the slag remaining with the metal, an inert gas is introduced below the surface thereof to promote the reduction of dissolved oxygen by the dissolved carbon therein. In so doing, carbon oxide gases are formed which escape from the bath in bubbles of the inert gas.

An inert atmosphere may be established and maintained in the degassing vessel and above the metal by enclosing the top of the vessel with a cover which provides a relatively small opening for entry of the tapping stream, as well as for the exhaust of the spent gases. A stream of inert gas may then be dispensed into the space between the metal surface and the cover in a uniform nonturbulent manner by means of, for example, a separate injection distributor pipe having a plurality of holes therein. The pipe may be fastened to the underside of the cover. The amount of inert gas injected through this system into the headspace between the cover and the metal surface should preferably be on the order of 20.0 cubic feet per hour per square inch of open area in the cover through which the tapping stream may enter. Alternatively, where the openings in the cover are sufficiently small to maintain a positive pressure in the headspace, no additional inert gas beyond that bubbled through the metal would be required.

The inert gas should in all cases preferably be bubbled into the vessel from a point near the bottom thereof in a manner which will create a condition of minimum splashing at the metal surface with maximum gas-metal

contact. When it is desired to kill the steel without the use of a metallic deoxidizer the quantity of inert gas injected should be between 10 and 50 cubic feet at S.T.P. per ton of steel treated, however, this amount will generally be between 20 and 40 cubic feet per ton for most steels treated. The actual amount of inert gas required to completely kill the steel without the need for a metallic deoxidizer will be dependent upon the carbon content at tap of the material to be treated, when satisfying the requirement that the final percent carbon when multiplied by the final percent oxygen content is no greater than about 0.0002. We have found that when this carbon-oxygen product is achieved in the melt and not permitted to rise before solidification that a sound porosity-free product can be formed, and without requiring the addition of any metallic deoxidizer whatsoever. If an amount of inert gas is utilized to degas the melt, which is insufficient to reduce the carbon-oxygen product to this level the final product will exhibit porosity unless a minimum amount of metallic-deoxidizer is used.

The actual amount of inert gas required to reduce the carbon-oxygen product to about the 0.0002 level, for a particular metal to be treated may be determined by the following formula:

$$V = (n) \frac{1480(m)}{\frac{4}{3}C_1 - O_1} \times \log \frac{C_2 O_1}{C_1 O_2} - 645 (C_1 - C_2)$$

where:

V = the volume of inert gas in cubic feet per ton of steel at S.T.P.

n = the efficiency factor which must be determined empirically but can be assumed to be 1 initially

m = the "steelmakers" constant which is usually .002 for most steels. If a large quantity of alloying elements are present regular text book methods can be used to modify the normal value

C_2 = the desired final carbon content

$O_2 = .0002 / C_2$ = the final oxygen content of a carbon killed steel

O_1 = the initial oxygen content which is given by the real solution of the following equation

$$O_1 = \frac{.00015}{C_2} - C_2 \pm \sqrt{\left(C_2 - \frac{.00015}{C_2}\right)^2 + .006}$$

$C_1 = C_2 - \frac{3}{4}(O_1 - O_2)$ = the initial carbon content at which the inert gas begins to cause carbon and oxygen to react.

As previously indicated, during the inert gas injection period, we also establish and maintain an inert atmosphere in the vessel, above the metal surface, in order to prevent infiltration of contaminants which would react with the steel. For example, if air was to infiltrate into the vessel headspace, the splashing steel would pick up oxygen therefrom rendering the process unsuccessful.

Although the term "inert gas" usually excludes the use of nitrogen, there are some instances where nitrogen may be employed in our process with success. Generally, in cases where the steel to be treated does not contain any element having a strong affinity for nitrogen, such gas may be utilized for degassing purposes. For example, nitrogen would be unsuitable for use with steels containing chromium, titanium, zirconium or aluminum but may be used on many but not all carbon steels where experience has shown that it is either not picked up by the steel, or where it is, that there are no deleterious effects.

After the required amount of inert gas has been injected into the metal, the metal is poured into a mold under the protection of an inert atmosphere. This is necessary to preclude the pickup of oxygen until the mold is filled with metal. The ingot mold is also preferably purged with an inert gas before the teeming step.

In applying the invention to the continuous casting

process, the practice enumerated above for lowering the carbon-oxygen product to about 0.0002 should be followed in order to kill the steel without adding a metallic deoxidizing element. The molten steel flowing from the vessel to the tundish as well as the stream flowing from the tundish to the mold must be protected against the pick-up of ambient air. This may be accomplished by surrounding the metal streams with an inert gas sheath. To protect the metal in the tundish, an inert atmosphere must be established and maintained in the headspace above the metal. This may be accomplished by utilizing a covered tundish and injecting the inert gas therein as previously described for preventing infiltration into the degassing vessel.

This invention contemplates the alternative practice of degassing the melt directly in the tundish instead of in the degassing vessel. In such case it will be preferable, though not absolutely necessary to protect the stream entering the tundish from the vessel. Similarly, it would not be necessary in such case to utilize inert gas in the vessel.

If manganese or any other relatively non-oxidizable element, such as nickel, molybdenum, cobalt or vanadium is required to meet a specified composition, it can be added to the melt before the degassing step, during tapping, or 2 to 3 minutes before the end of the degassing period.

If an oxidizable element such as aluminum, titanium or zirconium is required to meet a specification, it can only be added to the melt during the last few minutes of the degassing step. The reason for this is that such elements must be stirred into the melt, but cannot be added when the oxygen level therein is still relatively high. If such materials are added prematurely, the oxygen present in the melt will not only prevent the attainment of the correct amounts of residual materials desired, but additionally will cause the formation of excessive non-metallic inclusions in the product.

The basic process of the invention will be illustrated by the following examples:

EXAMPLE I

It was desired to produce a killed steel completely free of metallic deoxidizers, as such steel would be ideally suited for continuous casting. A molten steel bath completely free of slag was produced containing approximately .04% carbon and .05% oxygen and only minor amounts of other elements. It was calculated using the equation previously given that about 40 cubic feet of argon per ton of steel would be required to reduce the carbon and oxygen to a level described by a carbon-oxygen product of .0002 which would result in a killed condition of the product. The melt was subsequently held until 45 cu. ft. of argon per ton had been bubbled through at which time it was poured through an argon atmosphere into an argon filled mold. The product made was practically free of gas evolution during solidification and had a final analysis of .015% carbon and .015% oxygen yielding a carbon-oxygen product of .00023.

The general process of this invention can be modified so as to enable the art to produce a high quality alloy steel, extremely low in non-metallic inclusions, and wherein the required amount of alloying elements added will substantially correspond to the actual residual alloy content desired in the product. This modified process is based upon the fact that as the level of carbon and oxygen is lowered by their reaction at the bubbles of inert gas, the oxygen activity in the steel is incrementally lowered. The effect of this condition is that less oxygen is available to react with any alloying elements which are later introduced into the melt, and therefore fewer non-metallic inclusions will be found in the final product. Moreover, where the residual alloying element to be added is also a killing agent, the total quantity of such material added, need only be slightly in excess of the residual alloy requirements in the product. The reason for this is

that the steel will already have been substantially deoxidized as a result of the inert gas treatment before the alloy addition is made. This will be illustrated by the specific practice for producing a low carbon non-aging deep drawing steel, which follows. The practice comprises tapping a furnace containing molten steel at a sulfur and phosphorus level below about 0.04% and a carbon level about 0.02% to 0.03% higher than the carbon level desired in the product. The tapped metal is transferred, substantially free of slag, into a ladle. Alternatively, the slag may be made substantially non-reactive with an oxygen scavenging material, as aforesaid. An inert gas selected from the group consisting of argon, krypton, xenon, helium and neon is then bubbled below the surface of the metal to promote the reduction of dissolved oxygen therein by the dissolved carbon therein, thereby forming carbon oxide gases which escape from the metal in bubbles of the inert gas. The quantity of inert gas bubbled into the metal should be on the order of 30 cubic feet at S.T.P. per ton of metal treated. Concurrently, with the inert gas bubbling step, an inert atmosphere is established and maintained within the vessel and above the surface of the metal therein, in order to prevent the infiltration of air therein. After the required quantity of inert gas has been injected into the metal, i.e., when the dissolved oxygen therein has been reduced to a level such that only a nominal amount of non-metallic inclusions will be produced, the required amount of aluminum, from 0.4 to 1.8 pounds per ton of steel treated, would be added to achieve the necessary residual content in the steel. For instance, if a residual content of 0.02 percent aluminum were needed then from 0.4 to 0.6 pounds of aluminum would be added per ton of steel or if 0.08 percent were needed then 1.6 to 1.8 pounds per ton would be added. Manganese is preferably added during tapping or alternatively it may be added with the aluminum addition. The amount of manganese added depends on the required residual content of manganese in the steel. If this residual was 0.20 percent then 4 pounds of manganese would be added per ton of steel or if it was 0.60 percent then 12 pounds per ton would be added. Thereafter, the metal is poured into a mold while air is excluded from contacting it until the mold is filled with metal. This may be accomplished by surrounding the teem stream with a sheath of inert gas, and by using a mold which has been purged with inert gas. Alternatively, it is possible although not preferable to employ a non-oxidizing gas for this purpose, although such gas is not inert.

EXAMPLE II

It is desired to produce a high quality low carbon, non-aging deep drawing steel having the following specification: 0.05% C, 0.009% Si, 0.40% Mn, 0.03% S max., 0.01% P max. and 0.05% Al.

Three hundred tons of steel is tapped into a ladle from an open hearth furnace after the sulphur and phosphorus have been reduced to within the prescribed limits, the silicon essentially eliminated, manganese at a nominal value and the carbon content reduced to 0.08 percent. During tapping and for a time after tapping is complete, argon is bubbled through the steel from the bottom of the ladle until 9600 cubic feet (32 cu. ft. per ton) has been injected. At the end of this injection period 2400 lb. of manganese (8 lb. per ton) and 360 lb. of aluminum (1.2 lb. per ton) are added and argon bubbling is continued thereafter for about four minutes. The ladle of treated steel is then taken to a set of ingot molds and the steel is teemed through an argon atmosphere into the molds which have been filled with argon just prior to teeming. The argon atmosphere through which the steel is teemed is provided by an argon dispensing shroud which is attached to the bottom of the ladle around the ladle teeming nozzle.

What is claimed is:

1. A method for producing a killed steel which is sub-

stantially free of non-metallic inclusions which comprises: providing a mass of molten steel within a degassing vessel, said mass of steel being substantially free of oxidizing slag and having been refined to the desired level of metal-
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2. A method as claimed in claim 1 wherein the flow of said inert gas is stopped as soon as any slag which may be present on the surface of the molten steel enters the degassing vessel.

3. In a continuous casting process wherein molten steel is transferred to a tundish positioned in alignment with a continuous casting mold and wherein a continuous stream of the steel is discharged from a nozzle in the tundish into and through the mold, the improvement which comprises bubbling a quantity of inert gas below the surface of the steel in said tundish in order to promote the reduction of dissolved oxygen therein by the dissolved carbon therein, said quantity of inert gas being sufficient to lower the levels of carbon and oxygen in the steel to a point wherein the percent oxygen content when multiplied by the percent carbon content is no greater than about 0.0002; concurrently establishing and maintaining an inert atmosphere within the tundish and above the surface of the steel in order to prevent the infiltration of air thereinto; and pouring a stream of the steel from the tundish into the continuous casting mold while surrounding said stream with an atmosphere of inert gas in order to substantially prevent its contamination with air before its solidification.

4. A method for producing low carbon non-aging deep drawing steel which comprises tapping a furnace containing molten steel at a sulfur and phosphorus level below 0.04% and a carbon level greater than the desired

maximum level thereof in the product; transferring the tapped metal substantially free of oxidizing slag into a degassing vessel; adding manganese to said metal in an amount substantially corresponding to the desired residual quantity thereof in the metal; introducing a flow of inert gas below the surface of the metal in said degassing vessel to promote the reduction of dissolved oxygen by the dissolved carbon in said metal and thereby form carbon oxide gases which escape in bubbles of said inert gas; simultaneously establishing and maintaining an inert atmosphere within said degassing vessel and above said metal to prevent infiltration of air thereinto; thereafter adding aluminum to said metal in an amount substantially corresponding to the desired residual quantity thereof in the product, and thereafter pouring said metal into a mold while excluding air from contacting said metal until the mold is filled therewith.

5. A method as claimed in claim 4 wherein said inert gas consists of argon, and is bubbled into the molten steel in an amount between 20 and 40 cubic feet at S.T.P. per ton of steel treated.

6. A method as claimed in claim 4 wherein the amount of aluminum added to said metal is between 0.4 and 1.8 lbs./ton of said metal.

7. A method as claimed in claim 4 wherein the amount of manganese added to said metal is between 4 and 12 lbs./ton of said metal, depending upon the required residual content of manganese in said metal.

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