United States Patent

[11] 3,621,903

[72] Inventors Yuzuru Doi;
Kozo Yamada, both of Kawasaki-shi, Japan
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[73] Assignee Nippon Kokan Kabushiki Kaisha
[32] Priority Dec. 26, 1966
[33] Japan
[31] 41/84488

[54] **METHOD OF BOTTOM CASTING STEEL INGOTS USING LOW VACUUM OF FROM 610 TO 310 MM. HG ABSOLUTE**
4 Claims, 15 Drawing Figs.

[52] U.S. Cl. 164/65, 164/107, 164/119, 164/66, 164/259, 164/256
[51] Int. Cl. B22d 27/16
[50] Field of Search 164/62, 63, 61, 65, 66, 119

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Primary Examiner—J. Spencer Overholser
Assistant Examiner—V. K. Rising
Attorney—Robert D. Flynn

ABSTRACT: Molten steel is bottom poured into a mold, the internal gas pressure of which is maintained within the range of 610–310 mm. Hg absolute for a major part of the casting period. When the molten steel in the mold reaches a certain height, the mold is sealed against further exhaust of gas. Molten steel is continued to be poured into the sealed mold until the mold is filled, volatile components in the molten steel being thereby prevented from escaping from the sealed mold.

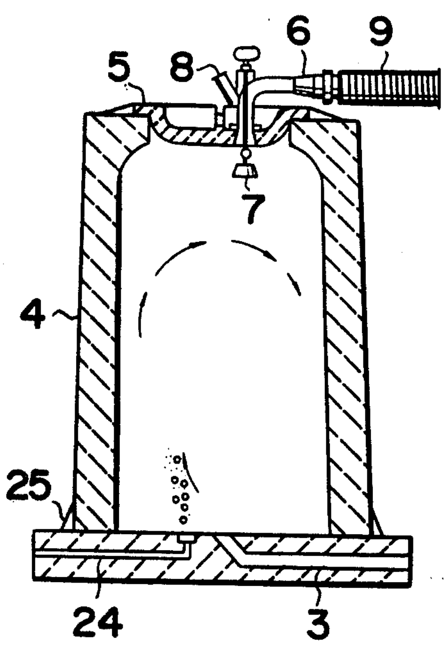


FIG. 1

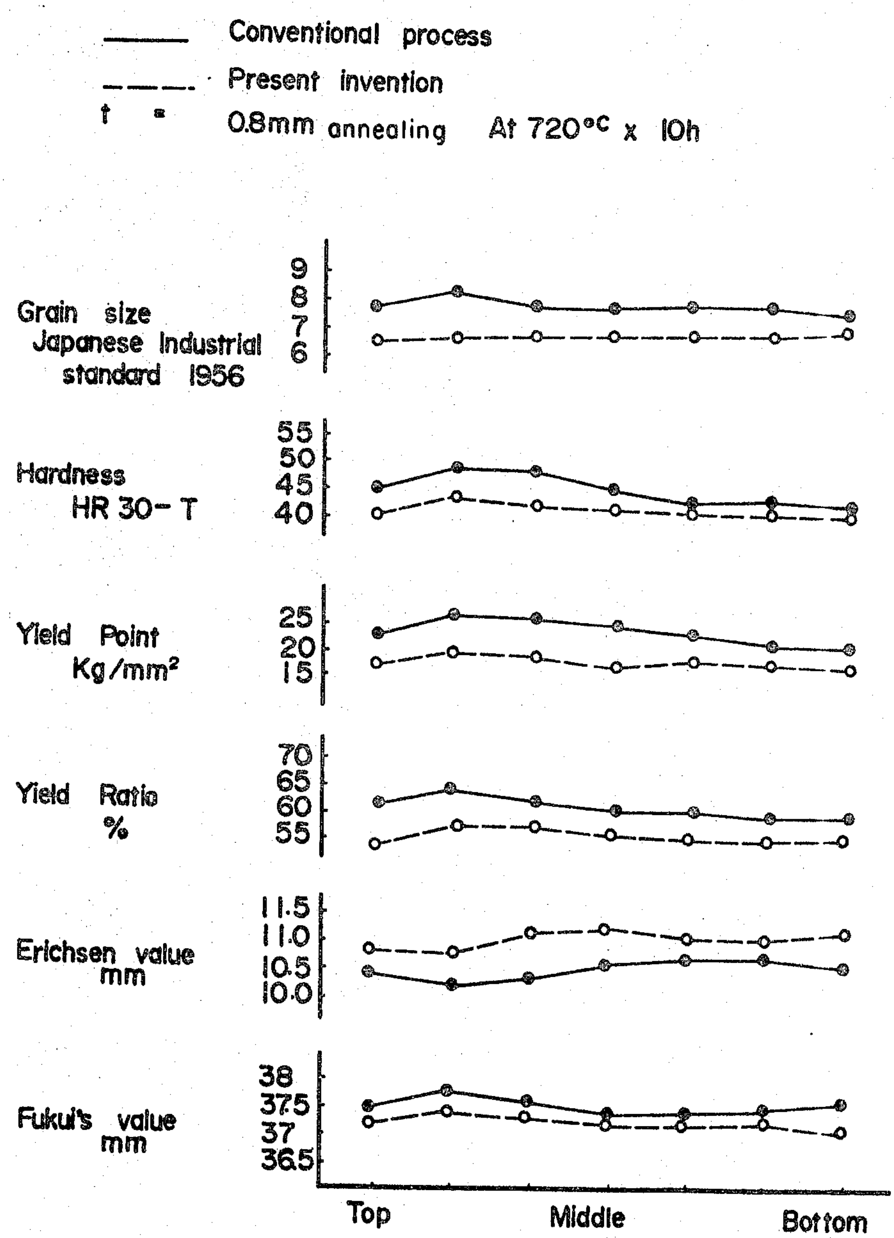
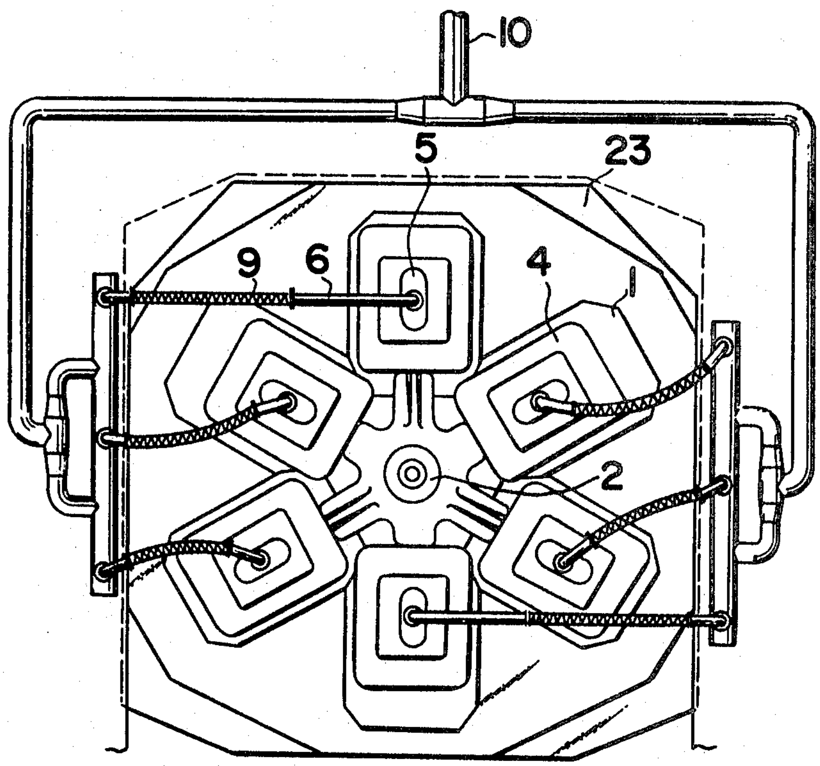

Conventional process
Present invention
t = 0.8mm annealing At 720°C x 10h
Grain size
Japanese Industrial standard 1956
9
8
7
6
Hardness
HR 30-T
55
50
45
40
Yield Point
Kg/mm²
25
20
15
Yield Ratio
%
70
65
60
55
Erichsen value
mm
11.5
11.0
10.5
10.0
Fukui's value
mm
38
37.5
37
36.5
Top
Middle
Bottom

FIG. 2a



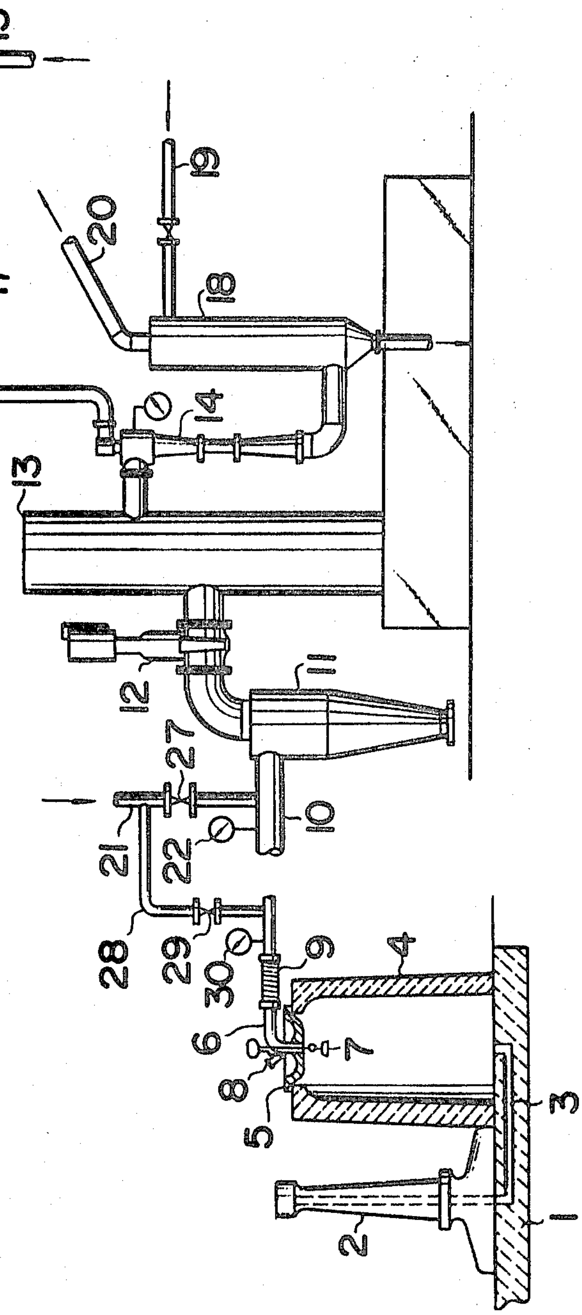


FIG. 2b

FIG. 2D

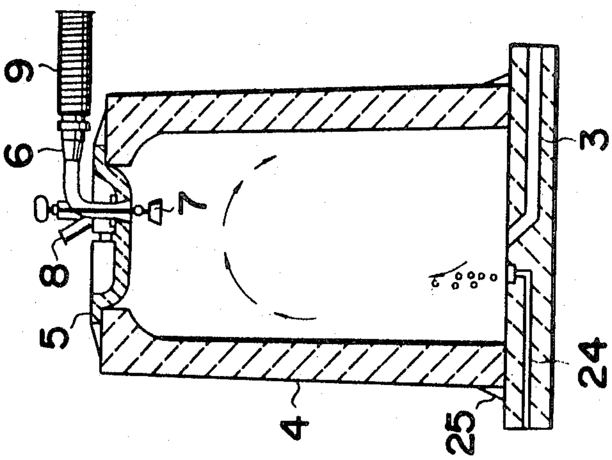


FIG. 2C

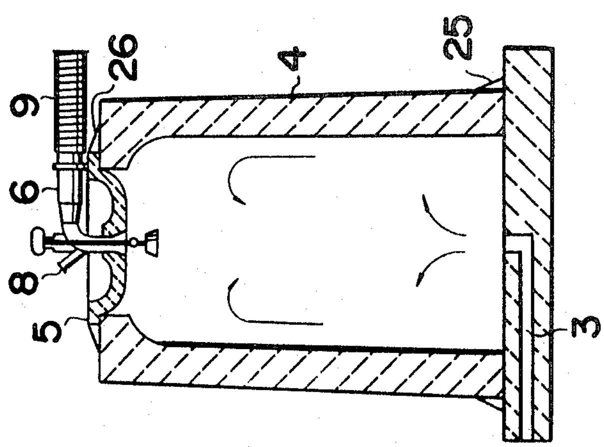
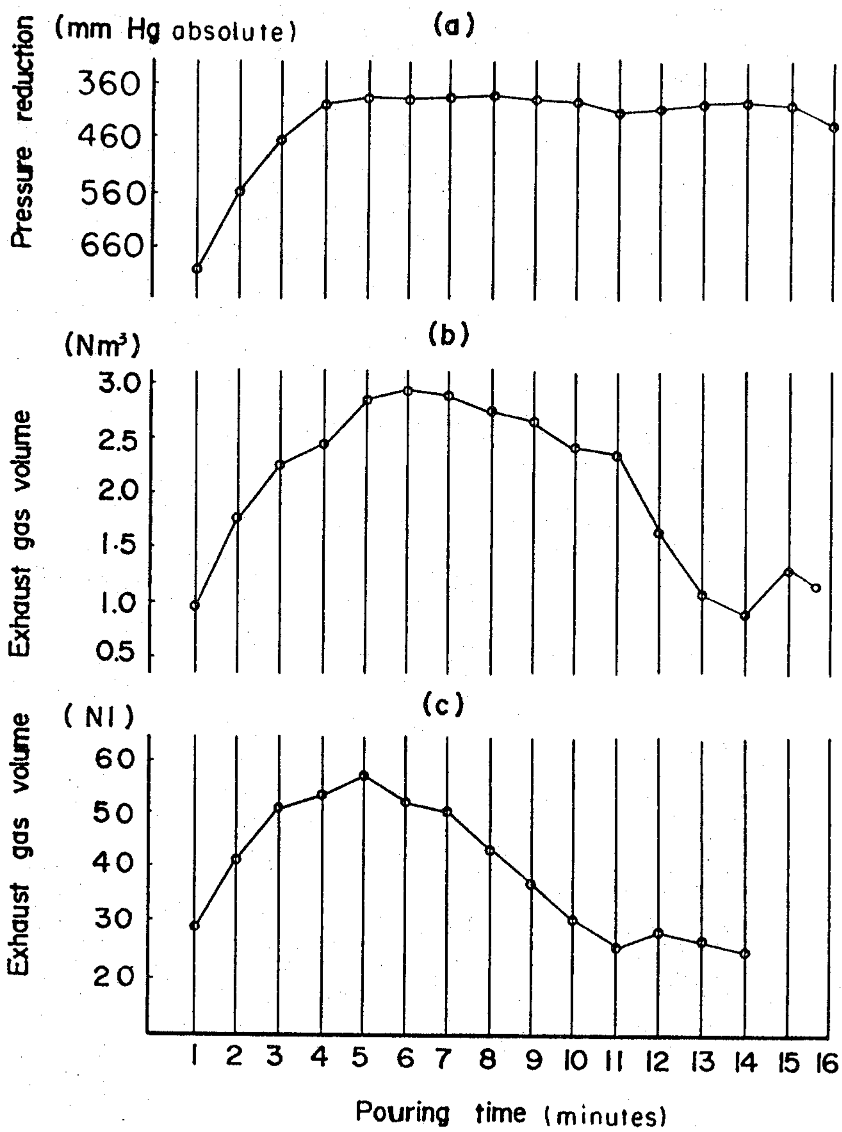


FIG. 3



Where N = State of the gas under one atmospheric pressure at 0°C [Figs. 3(b) and 3(c)]
m^3=Cubic meter [Fig. 3(b)], and
l = liter [Fig. 3(c)].

FIG. 4

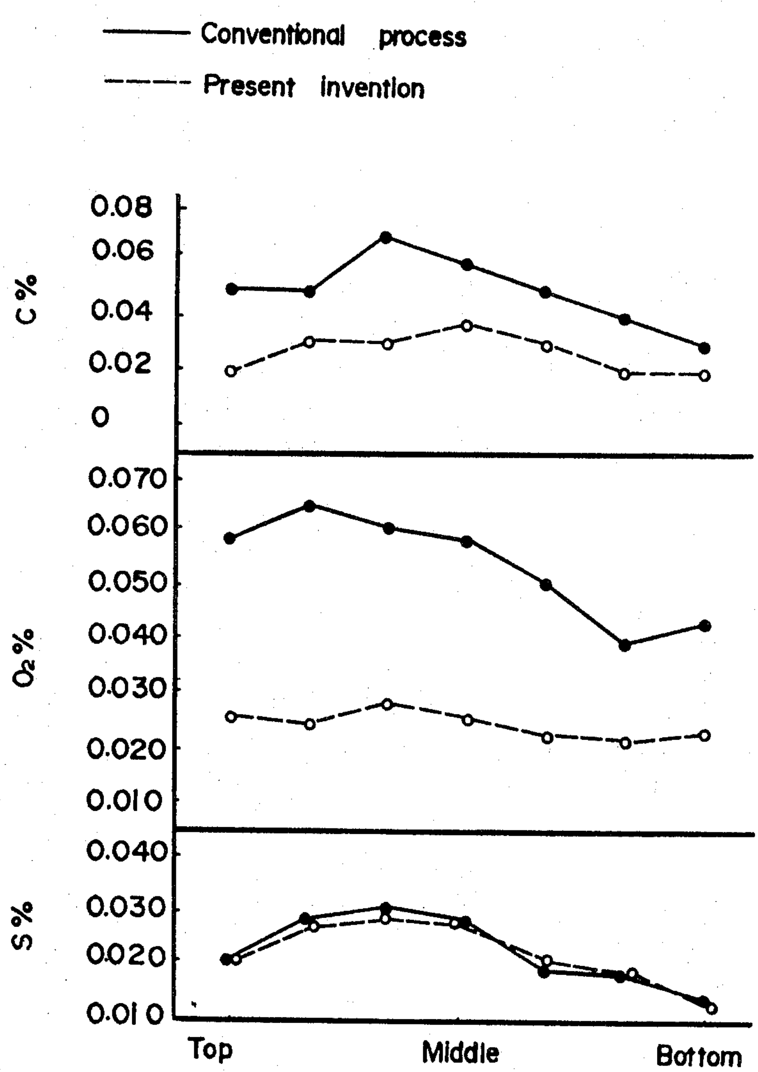

Conventional process
Present invention
C %
0.08
0.06
0.04
0.02
0
O2 %
0.070
0.060
0.050
0.040
0.030
0.020
0.010
S %
0.040
0.030
0.020
0.010
Top
Middle
Bottom

FIG. 5

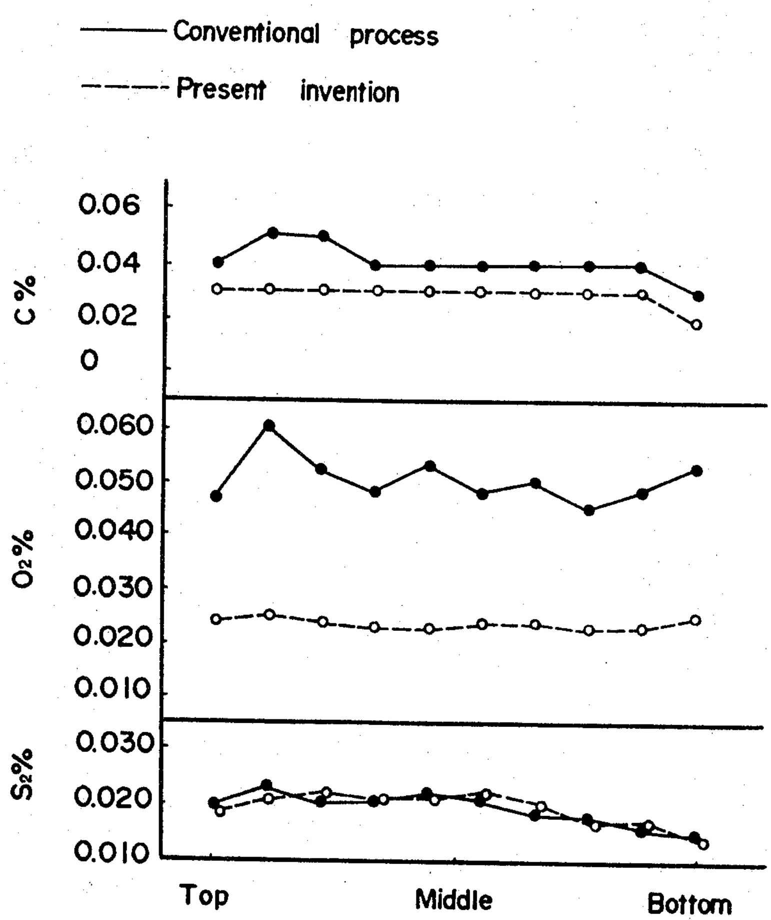

Conventional process
Present invention
C %
0.06
0.04
0.02
0
O_2%
0.060
0.050
0.040
0.030
0.020
0.010
S_2%
0.030
0.020
0.010
Top
Middle
Bottom

FIG. 6a

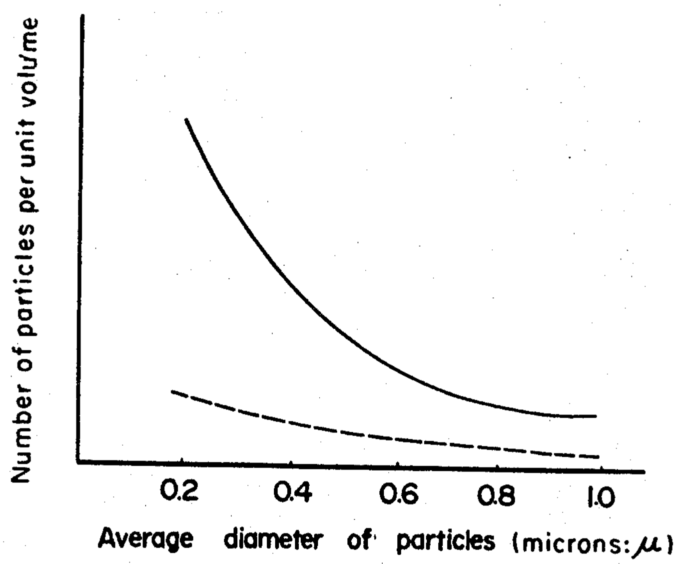

Number of particles per unit volume
0.2
0.4
0.6
0.8
1.0
Average diameter of particles (microns: μ)

FIG. 6b

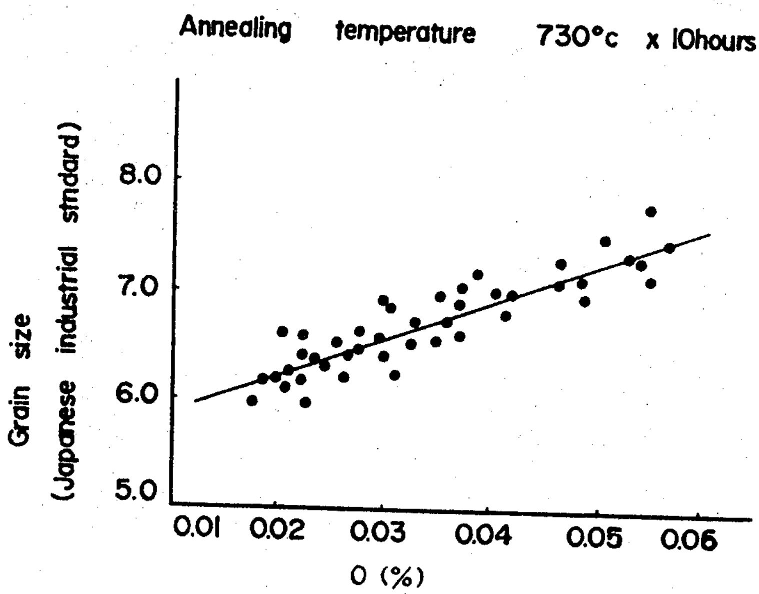

Annealing temperature 730°c x 10hours
Grain size (Japanese industrial standard)
8.0
7.0
6.0
5.0
0.01
0.02
0.03
0.04
0.05
0.06
O (%)

FIG. 6c

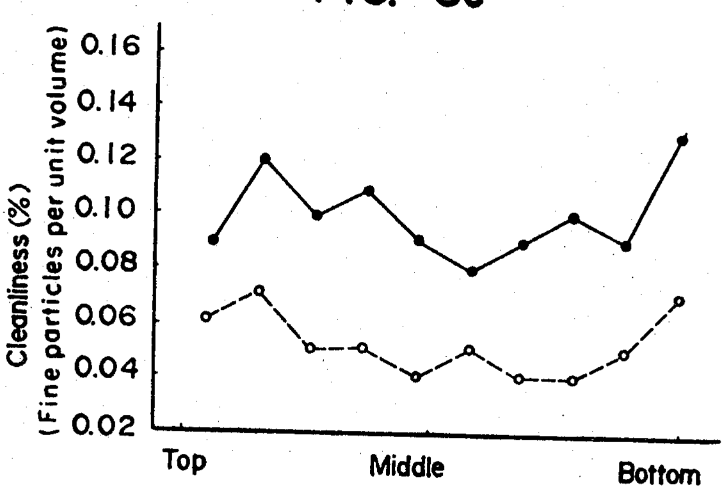

Cleanliness (%) (Fine particles per unit volume)
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Top
Middle
Bottom

FIG. 7a

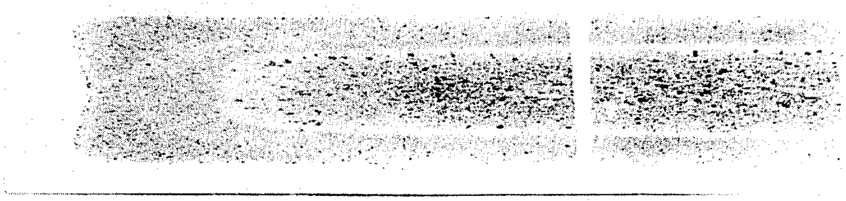


FIG. 7b

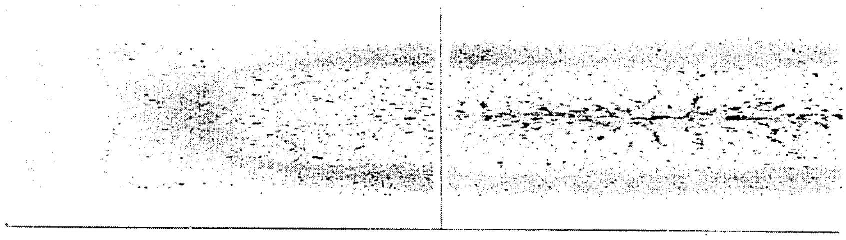


FIG. 7a1

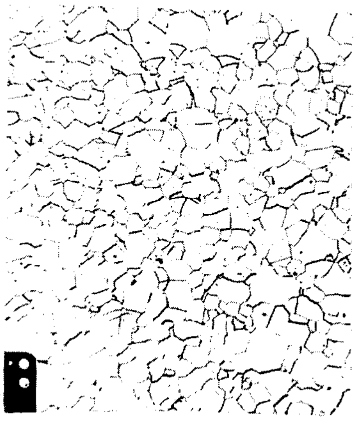
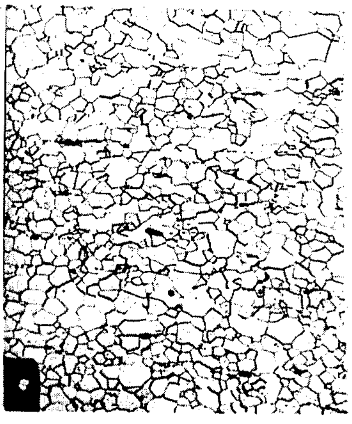


FIG. 7b1



METHOD OF BOTTOM CASTING STEEL INGOTS USING LOW VACUUM OF FROM 610 TO 310 MM. HG ABSOLUTE

The present invention relates to methods for reduced pressure casting of steel by a bottom pouring process, and particularly for production of low-carbon steel sheet suitable for press forming.

It is well known in the art that harmful constituents in metals, especially gaseous components, have substantial effects on the characteristics of the metals. Much has been said or written about reducing or eliminating such harmful gaseous components. For example, the properties of structural or special steels are adversely affected by the presence of harmful gases such as hydrogen, and a great number of proposals have been made to reduce the amount of said gases. Among those proposals, the vacuum degassing process for liquid metal has been established as the most effective and convincing method.

Very often, such vacuum treatment has been explained in papers discussing the manner of carrying out the treatment. One characteristic common to all of these vacuum degassing processes is the extremely high vacuum employed. However, in daily operation aiming at mass production, it is not easy to obtain as high a degree of vacuum as 1 mm. Hg, which is quite commonly required with such vacuum treatment. Moreover, it costs a great deal for the manufacture and maintenance of the necessary apparatus. At the same time, the vacuum treatment requires additional process steps as compared to the conventional methods, which increases manufacturing costs unnecessarily. However, in manufacturing high-class steel such as special steel, vacuum treatment has been put into practice without any trouble, because the advantage gained by the quality improvement is greater than the disadvantage of said cost increase. On the other hand, when applied to large-scale manufacturing of relatively low-quality steel sheets for pressing, the cost increase is not warranted.

As mentioned above, the vacuum treatment involving said two cost-increasing factors cannot be applied economically to a low-carbon steel for press forming, unlike in the case of special steels. In spite of these obstacles, unending efforts have been made to introduce the vacuum treatment method for the common materials, for example, as described in Japanese Pat. publication No. 1853/1962 and German Pat. No. 1,171,118. The Japanese patent publication is characterized by the construction of the sprue runner leading to the mold; and the German patent is characterized by the exhaust of the air after molten steel reaches a predetermined height in the mold. These inventions reduced the process steps. However, the other factor regarding the production, i.e. preservation and maintenance of the high vacuum, still remains unsolved, this being influenced by the conventional conception of requiring a high vacuum for the special steel. The difficulty in dealing with this problem is reflected in the special seal device provided by said Japanese Pat. publication No. 1853/1962 and the statement in said German Pat. No. 1,171,118 that the inside pressure of the casting mold be 30–160 Torr.

In order to improve the present situation wherein an effective and proper vacuum treatment for mass-produced items like low-carbon steel for press forming has not yet established, we have developed a new process and apparatus after various experiments, substantially improving the mechanical properties of steel sheets without cost increase. After a thorough investigation of the causes impairing the mechanical properties of ordinary steel sheets for press forming, it was found out that the quantity of ultrafine inclusions of less than 1μ in particle size included in steel has the greatest adverse influence on the properties of the steel. It was also found that these ultrafine inclusions could not be easily removed in the ordinary steelmaking process. It was established that the quantity of said ultrafine inclusions depends on the quantity of oxygen dissolved in the steel. From various experiments, we have established the limits of free oxygen at which the influence of ultrafine inclusions cannot be ignored. The present invention, as developed from this viewpoint, requires no high vacuum at all.

With very simple apparatus and a low degree of vacuum, the mechanical properties of steel sheets for press forming can be improved.

The main object of the present invention is to improve the mechanical properties of hot- or cold-rolled steel sheets for press forming. By the present invention, steel sheets for deep drawing with uniform quality can be produced, requiring no decarburization annealing, except in special cases.

Another object of this invention is to limit any cost increase in making steel ingots. The process of the present invention is so simple that it imposes no burden on daily operations and has no ill effect on productivity.

The nature of the present invention and other objects will be more apparent from the following description of preferred embodiments taken in conjunction with the accompanying drawings in which:

FIG. 1 is a graph of mechanical properties over the whole length of cold-rolled strip made by the process of the present invention;

FIGS. 2a–2d illustrate an apparatus for carrying out the present invention;

FIG. 3 presents three graphs showing changes of exhaust gas volume with time by using the present invention in comparison with the usual process of pouring into a mold;

FIG. 4 illustrates the variation in distribution of some elements throughout the height of an ingot made by the present invention in comparison with a conventional ingot;

FIG. 5 shows the corresponding distribution of elements along the length of a coil rolled from the ingot of FIG. 4, indicating the portions of the ingot from which the various test positions along the length of the coil have been derived;

FIGS. 6a–6c show various test results which are explained hereinbelow; and

FIGS. 7a–7b1 show sulfur prints of a middle slab from the ingot of FIG. 4 and microstructures of the final product made from said ingot.

From various experiments it was found that with low-carbon rimmed steel including about 0.06 percent carbon, a quantity of dissolved oxygen amounting to 0.045–0.060 percent, had a worse-than-anticipated influence on the mechanical properties of steel sheets. As will be apparent from FIG. 6a, ultrafine inclusions of less than 1μ (i.e., 1 micron) progressively increase as the diameter of its grain decreases. When the crystal structure was observed with an electronic microscope of 34,400 magnification, it was found that said ultrafine inclusions not only hindered the growth of crystal grains to a great extent, but also increased in number disproportionately at the smallest sizes as shown in FIG. 6a. Experiments were made by changing the content of dissolved oxygen to confirm that a border line of dissolved oxygen content was about 0.030 percent. That is, as shown by the dotted line in FIG. 6a, if the content of dissolved oxygen is reduced to less than 0.030 percent, the ultrafine greatly decrease greatly in the number, indicating no hindrance of grain growth and resulting in well-balanced growth. In addition, it was also confirmed that if the oxygen content is reduced to around 0.010 percent, the corresponding improvement was not obtained. In connection with FIG. 6a, FIG. 6b indicates the summarized results regarding the effect of oxygen content on grain size.

From the above-described experiments, it is clear that for the improvement of the mechanical properties of steel sheets for press forming, it is necessary and sufficient to reduce the dissolved oxygen content in the steel to less than 0.030 percent. According to experiments, it has been established that it is quite easy to satisfy this requirement by reducing the pressure by about 150–450 mm. Hg without the need for the high vacuum as required in the prior art.

It was found that in the case of less than 150 mm. Hg below atmospheric pressure, it is very difficult to reduce the free oxygen content to less than 0.030 percent, and it is needless to have a reduced pressure of more than 450 mm. Hg below atmospheric pressure.

In the present invention, there is no need for a special operation to add oxygen for relatively higher carbon content or to add carbon for lower carbon content which is a very common practice in the prior art. When the present invention is applied to the molten steel itself tapped as low-carbon steel for press forming, quite favorable results are obtained.

As recommended in the present invention, reducing the pressure to 150–450 mm. Hg below atmospheric pressure, that is, an absolute pressure of 610–310 mm. Hg, can be satisfactorily carried out with the ordinary casting process and gas exhaust system. No ill effects occur even if the air exhaust is made at the same time as starting the steel pouring. Due to the considerable amount of air remaining in the exhaust pipes and casting mold, it takes a certain time to attain the required reduction in pressure. Accordingly, at the height of rimming action, the required pressure reduction can be obtained in a natural and smooth manner.

According to experiments, in ordinary bottom casting at atmospheric pressure, the exhaust gas flow due to displacement and generation of gases reaches its peak about 5 minutes after starting the steel pouring. FIG. 3(*c*) shows the change of exhaust gas volume in the progress in time under experimental conditions as follows.

Kind of steel:	ordinary rimmed steel including 0.06 percent carbon
Casting:	bottom casting of 13.8 tons at standard atmospheric pressure. casting speed: about 1 ton/min. forced ceasing of rimming action after 13 minutes.
Exhaust gas:	

9calculating total amount of CO_2, CO and H_2 exhausted per 1 min.

It is apparent from this figure that in the bottom casting, the exhaust gas flow reaches its peak about 3–7 minutes after starting the steel pouring. This time may vary more or less, depending on the prescribed weight or casting speed. However, it is necessary to arrive at the required pressure reduction in a casting peration according to the present invention before reaching the peak of exhaust gas flow. After this, it is required that the said pressure reduction should be maintained until the exhaust gas flow ceases, thus reducing the oxygen content dissolved in the steel without difficulty.

In the present invention, the mold is sealed by mechanical closure means at the upper part of the casting mold. The molten steel is forced against the cap containing the above closure means.

In this device, gas that is trapped above the molten steel by the closure of the outlet is forced to disperse into the molten steel, which ensures unprecedented uniformity of internal characteristics of steel ingots. It is important to close said outlet under reduced pressure, before the hitting of the cap by the molten steel. The time up to hitting the cap may be properly determined according to the composition of molten steel. The pouring of the molten steel is continued until the steel hits the cap after the flow of exhaust air ceases. According to the present process, the internal characteristics of steel ingots have been improved much more than by the conventional process, due to the substantial decrease of said fine inclusions as well as the forced stopping of the rimming action by the hitting cap. The first advantage is that the tubular blowhole, quite common to ordinary capped steel (i.e., that cast at atmospheric pressure), is extremely small and dispersed. The second is the absence of any tendency for said fine inclusions to cohere around said blowhole. The third is the formation of sound rim layers, with no skin holes. These internal characteristics naturally have good effects on hot- and cold-rolled steel sheets, such as removal of linear flaws, linear scale and blow flaws, and uniform mechanical properties in steel sheets. The present invention provides a very good casting method for steel ingots to be manufactured into steel sheets for press forming.

Another advantage of the present invention lies in the easy and stable improvement in aging properties of steel sheets. That is, at the mechanical closure of mold outlet, the amount of free oxygen dissolved in the steel is already substantially reduced, so that if at this period V, B, Zr, Ti and Al are added, the nitrogen in the steel is most effectively fixed because of the oxidation loss being kept to a minimum.

Experiments indicate that whatever the above addition agent may be, the yield was high, and 80–90 percent of the nitride was uniformly distributed. The required amount of addition agent can be most effectively applied from the center runner before said mechanical closure. When a certain amount of molten steel is poured after said closure, there is no ill effect even if the addition period of the nitrogen fixation agent extends over the above pouring time of the molten steel. To delay the aging of steel sheets for press forming, the best method is to add the nitrogen fixation agent into the center runner during the mechanical closure.

A preferred embodiment of the present invention is illustrated in FIGS. 2*a*–2*d*. FIG. 2*a* is a plan view of a system for exhausting gas from each mold using the stools shown in Japanese Utility Model Publication 11,517/1962. FIG. 2*b* is a layout of a complete exhausting system in the present invention, and FIGS. 2*c* and 2*d* are enlarged views of the molds of FIGS. 2*a* and 2*b* and show diagrammatically the flow of molten steel in the molds during the exhausting of the gases.

In the above drawings, FIGS. 2*a*–2*d*, the stools **1** are assembled with the required number of smaller stools which are radially arranged around the center runner **2** stool and are fixed on a truck **23**. Molds **4** are placed on each of the above smaller stools and each are provided with caps **5** having exhaust pipes **6** to be coupled to flexible tubes **9** by means of flanges. Flexible tubes **9** placed on each mold are, singly or by groups, collected to a main exhaust pipe **10**. The relation between exhaust pipe **6** and caps **5** is illustrated in a vertical section in FIG. 2*b*, and includes a bell-type plug **7** and a peephole **8**. In each cap **5**, a hole is made to accept the exhaust pipe **6** and the lower part of this hole is shaped to fit the bell-type plug **7**. The cap **5** and a pipe **6** are connected together by suitable means such as a flange joint. The plug **7** is hung on a rod which passes through a suitable hole and pipe **6**, in order to move freely vertically. Molten steel poured into the center runner **2**, goes through the runner **3** into the mold **4**. After the elapse of a required period of time, the bell-type plug **7** is raised up to meet the cap **5**, so that the exhaust is shut off. During the period molten steel is poured, it is frequently necessary to make a pressure adjustment according to the state of the rimming action. For this purpose, it is very effective to make observations with the naked eye through the peephole or window **8**.

The main pipe **10** of the exhaust air system is connected with cyclone **11**, in which dust of comparatively coarse particle size is eliminated. Cyclone **11** leads to a shutoff valve **12** and a vacuum tank **13**. As earlier mentioned, the gas exhaust process of the present invention is principally characterized by its low degree of vacuum, so that the vacuum tank does not require an especially high vacuum. A pressure reduction to about 600 mm. Hg absolute at most is sufficient. Accordingly, a steam ejector **14** of rather low capacity suffices. The steam for the ejector **14** is properly reduced through pressure-reducing mechanism **16**. In FIG. 2*b*, bypass line **17** is added, which is desirable in daily operation. Exhaust gas, from which fine dust has been removed by cooling water from pipe **19** in condenser **18**, is removed through line **20** into the outer air.

The present invention can be easily designed and manufactured, and in practice, various modifications can be made. The most important feature is to keep constant all the conditions prior to the vacuum tank **13** to obtain stable operation. In other words, it is essential to maintain the steam pressure prior to ejector **14** at a definite value, so that the degree of vacuum within the vacuum tank **13** is maintained at a constant level. According to experiments, it has been found that the control of the amount of pressure reduction by means of said steam pressure, is not always adequate. To meet this difficulty, a pressure reduction control device is provided by introducing air at proper points before cyclone **11** and after each mold. The vacuum control within each mold can be carried out smoothly and the response of the vacuum level to the change of air input was more rapid and stable than had been expected. At the same time, the pressure-reducing control to each mold is easily carried out according to the rimming action observed from the peephole **8**.

In FIG. 2*b*, **21** represents an air introduction line, having a regulating valve **27** with a gauge **22** for main exhaust pipe **10**. This can be used to adjust the pressure for the molds as a whole.

Further, each mold has a branch pipe **28** equipped with its own regulating valve **29** and reducing pressure gauge **30**. As the first step in operating this mechanism, it is recommended that the interior of vacuum tank **13** be maintained at the required degree of vacuum, by closing valve **12** and the respective regulating valve **29** for each mold, while opening the main regulating valve **27** for exhausting gas. Then, if on pouring the molten steel, the valve **12** is opened and air-regulating valve **27** is gradually closed, it is easy to control the pressure reduction. At the same time, it is preferable to make adjustments by opening regulating valve **29** according to the rimming action in the mold.

The exhaust outlet of a mold may be placed in any position in relation to cap **5**. As shown in FIG. 2*b*, such an outlet is located at the center of said cap **5**. From observations through the peephole **8**, the molten steel can be expected to follow the path indicated by arrows in FIG. 2*c* after it is poured through sprue runner **3** into mold **4**.

The advantages of the present invention can be fully realized with the device shown in FIG. 2*c*. However, if the exhaust outlet of the cap is made slightly off its center, it will lead to more effective results. FIG. 2*d* is an example of an exhaust outlet placed to one side of the longitudinal centerline of the mold. In this example, the molten steel in the mold follows the path shown by arrows in said figure. The path can be observed from the peephole **8**. The inclination of the sprue runner **3** and introduction of inert gas **24** indicated in FIG. 2*d* are intended to accelerate said convection current (or movement). Said convection current is an ideal path of agitation for molten steel, and is superior to the backflow shown in FIG. 2*c*.

The manner in which the present invention achieves the desired objects will be more fully understood from a consideration of the following results with a preferred embodiment of the invention.

Condition of molten steel:

about 83 tons of ordinary molten rimmed steel containing 0.05 percent carbon, blown by LD converter.

Condition of casting:

among five molds placed on the assembled stool shown in FIG. 2*a*, the ordinary steel casting process was employed in two of the molds, while the molten steel poured into three of the molds was processed by the present inventive process.

casting weight: 16.5 tons

casting speed: about 1 ton/min.

Sealing with ordinary silica mortar was done, as indicated at **25** and **26** in FIGS. 2*c* and 2*d*.

Conditions of pressure reduction in the three molds:

The exhaust outlet of the cap was fixed as illustrated in FIG. 2*d*. The vacuum within the vacuum tank is 260 mm. Hg absolute before commencement of the pour.

The operation was carried out so that the pressure within the mold reached 490 mm. Hg absolute within 4 minutes after pouring (the vacuum tank pressure being at 260 mm. Hg absolute).

Condition of capping:

Fifteen minutes after starting to pour the bell-type plug **7** was pulled up to shutoff the exhaust gas outlet, and after another 40 seconds of pouring, the shutoff valve **12** was closed.

About 1 minute after raising the plug **7** the molten steel hits the cap **5**; a similar period was required in the case of the ordinary capped steel processed in the other two molds.

FIG. 3*a* indicates the actual pressure curve for any one of said three molds, as measured at minute intervals. FIG. 3*b* shows the exhaust volume per minute of CO_2, CO and O_2), again for one of said three molds. The similarity of the curve of FIG. 3*b* and the curve of FIG. 3*c*, which shows the exhaust volume of said three components in the conventional casting operation at atmospheric pressure, is due to the fact that the degree of pressure reduction reached at 4 minutes after starting the pour in, maintained substantially constant until the finish of casting. FIG. 4 shows the component contents for an ordinary capped steel ingot (solid line) and a steel ingot made by present invention (broken line), both of which were cast from the same molten steel at the same time in the presently described example.

It is apparent from this experiment that the present invention, in spite of its low degree of pressure reduction, ensures far better uniformity than the ordinary casting process for capped steel. Especially in the described embodiment, the oxygen content of 0.060 percent is quite uniformly distributed from top to bottom of the steel ingot and is maintained within a range of 0.022 to 0.028 percent. Therefore, it is not necessary to maintain the high vacuum (of about 30–160 mm. Hg absolute) as is required in German Pat. No. 1,171,118. The excellent uniformity, as shown by dotted lines in FIG. 4, is entirely due to the effect of the molten steel hitting the cap after closure of the exhaust outlet at reduced pressure. FIG. 4 covers analysis values measured at seven points spaced at the same interval along the centerline from top to bottom of the steel ingot.

Another advantage of the present invention is seen from the sulfur print of a transverse cross section taken near the center of a slab rolled from said steel ingot. FIG. 7*a* is a sulfur print of a slab made by the present process and FIG. 7 is a print of one made by the conventional process.

As will be apparent from these prints, the rim layer by the present process is of almost the same thickness (50–60 mm. equivalent of steel ingot) as in a usual capped process of the prior art. In the high vacuum treatment for rimmed steel, the thickness of the rim layer may be reduced to about half of that of the usual one. The successful maintenance of the rim thickness is the effect of molten steel hitting the cap after mechanically closing the exhaust outlet at low-pressure reduction to force the reaction to stop.

The second advantage observed from said prints is the good uniformity of the core. As clearly shown in the print of FIG. 7*b*, particularly in the case of capped steels of low carbon content, the central part of the core frequently presents some wrinkles due to shrinkage. On the other hand, according to the present invention, these wrinkles are entirely removed, with a uniformity and good properties, which are exemplified in the print of FIG. 7*a***1**).

Ordinary capped steel and capped steel produced by the present invention were converted into cold-rolled steel sheets under the same conditions as follows:

Condition of hot rolling:	
thickness of final sheet	2.3 mm.
finishing temperature	865° C.
coiling temperature	555° C.
Condition of cold rolling after pickling	
thickness of final sheet: actual value	
ordinary capped steel	0.89 mm.
capped steel by the present invention	0.81 mm.
annealing temperature	720° C. × 10 hours
temper rolling	1.2%

FIGS. **1** and **5–7** show the results of tests and measurements of the properties of the above-mentioned ordinary capped steel and the capped steel produced according to the present invention. In FIG. 1, "*t*" represents "thickness" of the strip and the hardness relates to Rockwell hardness test results. FIG. 5 shows the analysis value of the three components corresponding to those of FIG. 4. FIG. 6*c* indicates the degree of cleanliness corresponding to FIG. 6*a*, where cleanliness relates to the number of fine particles in an ingot per unit; FIG. 1 shows the mechanical properties; FIGS. 7*a*1) and 7*b*1) show the ferrite structures corresponding to FIGS. 7*a* and 7*b*.

The present invention may be summarized as follows. In order to obtain the most desirable press formability for steel sheets, it has been established that it is only necessary to maintain the free oxygen in the steel within the range of 0.030–0.020 percent. This requirement is achieved by a treatment under a pressure reduction to 610–310 mm. Hg absolute, at which low pressure a cap for the molten steel is provided having means for mechanically closing the exhaust outlet of the mold. When the final annealing is carried out at comparatively low temperature of 720° C. for 10 hours, very favorable results were obtained with a yield point of about 18 kg./mm.^{2} and the yield ratio of about 55 percent. Needless to say, if annealed at 730°–750° C., the ordinary temperature for deep drawing steel sheets, the mechanical properties listed in FIG. 1 are further improved, almost without requiring decarburization annealing.

Tests were also carried out on the improvement of the aging properties. A molten steel was prepared including the following composition in the ladle: C, 0.06; O_2, 0.055; N_2, 0.0010. After a similar treatment as given in said above embodiment at a pressure reduction of 400 mm. Hg at maximum, 0.3 kg. of an iron alloy containing 21 percent Boron (B) per ton was continuously added into the molten steel from the center runner 2, from about 3 minutes before closing of the exhaust outlet by the bell-type plug. This proved quite effective, because in this period the free oxygen dissolved in the molten steel was reduced to less than 0.030 percent. As a result, the cold-rolled steel sheets contained 0.004 percent boron. Said steel sheets' aging index was 2.1 kg. at 100° C. × 1 hr., which was a satisfactory delayed aging property. Other mechanical properties showed the same good values as mentioned hereinabove. Other addition agents mentioned earlier ensure similar good effects.

As above described in detail, the process and apparatus according to the present invention are significant enough to break down the conventional concept of vacuum treatment, for providing the most suitable steel ingot for press forming. Taking into consideration the fact that steel sheets for press forming are items of mass production, the present invention is useful and beneficial to the industry concerned, and involves almost no cost increase.

While we have described above a particular embodiment of our invention for the purpose of illustration, it should be understood that various modifications and adaptations thereof may be made within the spirit and scope of the invention as set forth in the appended claims.

What we claim is:

1. A method of bottom casting steel ingots suitable for press forming steel sheets comprising:
   bottom pouring molten steel into a mold having an opening at the upper portion thereof for exhausting gas from the mold, the internal gas pressure of said mold being maintained within the range of 610 to 310 mm. Hg absolute during said pouring and prior to the molten steel reaching the vicinity of said upper opening;
   closing said opening to seal the mold against further exhaust of gas when the molten steel poured into the mold reaches the vicinity of said upper opening; and then
   continuing bottom pouring of said molten steel into said mold, thereby dispersing trapped gas therein into the molten steel.

2. A method according to claim 1, wherein the oxygen content of the cast ingot is from about 0.01 percent to about 0.03 percent by weight.

3. A method according to claim 1 comprising:
   controlling the pressure within said mold by introducing air into an exhaust line of the mold.

4. A method according to claim 1 comprising:
   introducing inert gas into the mold bottom to improve the flow of molten steel.

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