

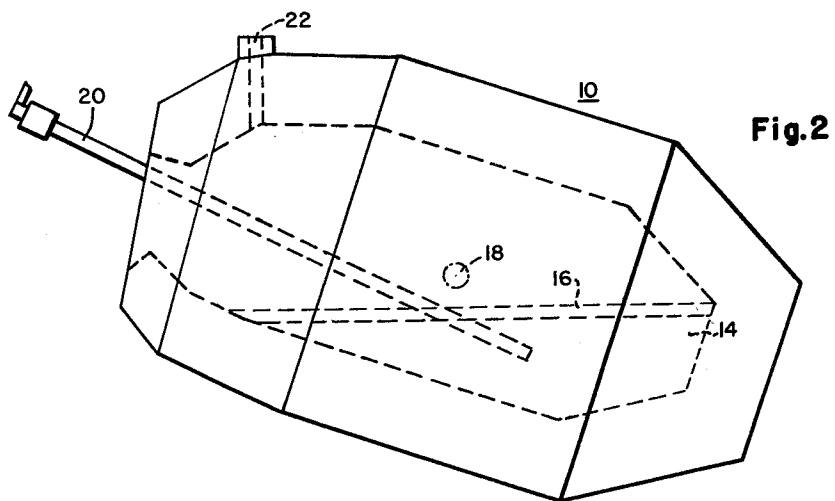
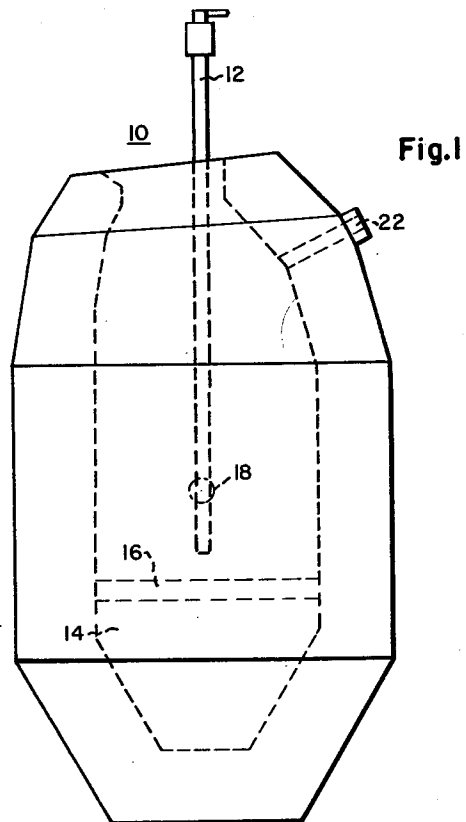
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PROCESS OF PRODUCING STEEL

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PROCESS OF PRODUCING STEEL

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This invention relates to a method or refining iron base metal to a low carbon content, and in particular to a method of producing electrical grade silicon iron ingots capable of being processed into grain oriented silicon steel strip.

Recently considerable publicity has been given to the refining of molten metal by a process known to the trade as the "LD Process" such as that taught by Patent 2,800,631, issued July 23, 1957, to Suess et al. Such a process has become commercial, particularly in the production of carbon steel, and employs the practice of top blowing of a molten bath of iron or iron and scrap by directing a vertical stream of high purity oxygen at high velocity onto the surface of the molten bath. Oxidizable elements of the bath provide the source of energy to maintain the bath in a liquid state until the desired refinement is attained.

While the known process is satisfactory for the production of steels having a carbon content ranging from about 0.05% to about 1%, it has been found to be unsatisfactory for the production of extremely low carbon content steels having a nitrogen content below 0.006%. In particular it has been found to be unsatisfactory to utilize the LD process for the production of silicon iron alloy having a carbon content of not more than 0.035% that is capable of being processed into grain oriented silicon steel strip.

In practicing the LD process it has been found that if such top blowing of a bath of molten iron is continued for a sufficient length of time to decrease the carbon content to below 0.05%, there is an insufficient reaction of oxygen with oxidizable elements in the bath at such low carbon contents to effectively generate effluent gases in sufficient volume to prevent siphoning air along with the flow of oxygen into the molten bath. Under such conditions, and in particular where the carbon content of the bath has been reduced to about 0.035%, such siphoning of air along with the penetration of the bath by the stream of oxygen, imparts a detrimental nitrogen content to the resulting alloy.

Further, in producing the refined steel by the LD process and where the vertical oxygen blow is utilized to produce a carbon content of not more than 0.035%, it has been found that the bath lacks the necessary fluidity and effervescence to permit ready attainment of a slag-metal equilibrium since the very nature of the process reacts to enhance the formation of a slag-metal emulsion; thus particles of slag remain entrapped and are present as inclusions when the refined metal is solidified in the form of ingots. Such inclusions are particularly detrimental where a silicon iron alloy is to be produced from the refined metal since such inclusions are entrapped in such a form that when the refined metal is alloyed with silicon a considerable portion of the inclusions is retained or entrapped in the steel and the resulting solidified ingot.

The presence of such inclusions in the refined metal, or in a resulting silicon iron ingot where such refined metal is alloyed with silicon, is highly undesirable. Such inclusions in particular have a detrimental effect on the final quality of grain oriented strip that is to be made from the silicon iron alloy that is produced from such refined metal. The inclusions can alter the process of secondary grain growth in such silicon iron steel and the development of texture therein with the result that the watt loss values and permeability of the final strip are impaired. In addition, the very presence of these inclusions in the

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resulting steel strip contributes to higher watt loss values and decreased permeability since they tend to restrict the movement of the magnetic domain walls. Further, surface quality of the final strip produced from such silicon iron alloy ingots is impaired, preventing the proper application of an insulating coating material that is utilized in conjunction with such strip.

Silicon iron alloy, to which reference has been previously made and which is often commonly called silicon steel in the industry, has heretofore been produced by the open hearth process which, in general, has made use of oxygen as described in Patent 2,580,164 issued January 1, 1952, to Slottman. While such open hearth melting has made possible the production of refined metal used for producing silicon iron ingots that can be processed into grain oriented silicon steel strip, the time delay encountered in effecting the melting and refining of the steel by the open hearth process is a distinct disadvantage which must be overcome in the commercial production of silicon steel. However as stated hereinbefore, the known LD process is unsatisfactory for producing silicon steel so that up to the time of the present invention there has existed no known process which will have the advantages, but not the disadvantages, of both the known LD process and the known open hearth practice for the production of silicon steel ingots.

An object of this invention is to provide for refining ferrous base metal by utilizing oxygen-blowing techniques to effect the refining and to lower the carbon content of such metal to not more than 0.035% without an accompanying entrapment of slag inclusions or the absorption of nitrogen in the resulting metal.

Another object of this invention is to provide for the production of silicon iron ingots by utilizing oxygen-blowing techniques to refine a molten iron bath to a carbon content of less than 0.035% without an accompanying entrapment of slag inclusions and the absorption of nitrogen in the resulting metal.

A further object of this invention is to provide for refining a bath of molten ferrous metal by direct vertical blowing of oxygen until the carbon content of the bath is reduced to between 0.06% and 0.20% and thereafter enlarging the surface of the molten bath and continuing the refinement by submerged blowing of the bath with oxygen to reduce the carbon content thereof to not more than 0.035% without the entrapment of slag or a pick-up of nitrogen.

A still further object of this invention is to provide for refining a bath of molten ferrous metal by the direct vertical blowing of oxygen until the carbon content of the bath is reduced to between 0.06% and 0.20% and thereafter enlarging the surface of the molten bath and continuing the refinement by a submerged blowing of the bath with oxygen at a rate less than the direct vertical blowing to reduce the carbon content thereof to not more than 0.035% without the entrapment of slag or pick-up of nitrogen and thereafter alloying the resulting refined ferrous metal with predetermined amounts of silicon to produce a silicon iron ingot of predetermined composition capable of being processed to produce grain oriented silicon iron strip.

Other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying drawing in which:

FIGURE 1 is a view of a typical converter in the vertical position as utilized in practicing a portion of the process of this invention, and

FIG. 2 is a view of the converter of FIG. 1 in a tilted position as utilized in practicing another portion of the process of this invention.

While this invention is applicable to the refining of molten ferrous base metal in general so that the refined

metal will have a carbon content of less than 0.035% without the entrapment of slag or an accompanying pick-up of nitrogen, the process to be described is particularly advantageous in the production of silicon iron alloys which have a silicon content in general of about 2.5% to 4% and preferably in the range of about 2.9% to 3.4%. The process will be described with particular reference to the production of silicon iron alloy, although it is to be understood that the refining of the metal to be described, up to the point where alloying additions are made to the refined ferrous base metal, is applicable to the production of other refined ferrous base metals. For the purpose of this invention, reference may be had to the following table in which there are listed a preferred general range and a typical specific analysis of the silicon iron alloy steel in the production of which the process of this invention may be used to great advantage.

Table 1

	Percent by Weight	
	General Range	Typical
Silicon.....	2.90-3.40.....	3.15
Carbon.....	.020-.035.....	.028
Manganese.....	.035-.10.....	.065
Sulfur.....	.035 max.....	.020
Phosphorus.....	.005-.020.....	.008
Aluminum.....	.05 max.....	.01
Copper.....	.050-.30.....	.080
Nickel.....	.030-.15.....	.050
Tin.....	.005-.020.....	.010
Iron.....	Bal.....	Bal.

Such silicon iron alloy steels have been produced successfully for years by the open hearth practice utilizing the refining process described in the Slottman Patent No. 2,580,614 referred to hereinbefore, and the resulting ingots have been processed into grain oriented silicon steel strip in accordance with the teaching of Patent No. 1,965,559, issued July 3, 1934, to Goss, Patent No. 2,084,337, issued June 22, 1937, to Goss, Patent No. 2,599,340, issued June 3, 1952, to Littmann et al., and more recently in accordance with the teachings of Patent No. 2,867,557 issued June 6, 1959, to Crede et al.

In accordance with this invention, hot molten ferrous metal such as is produced in a blast furnace or a hot blast cupola and which has a carbon content of around 4%, along with a quantity of steel scrap or iron ore, is introduced into the converter 10 illustrated in FIG. 1 by conventional means, the converter being provided with a refractory lining (not shown). The proportions of molten iron and scrap and/or iron ore will be usually determined by the metalloid constituents of the molten iron.

After the scrap and hot metal are introduced into the vertical converter 10, an oxygen lance 12 having an inner diameter of about one inch or larger is so introduced into the open top of the converter as to directly impinge a vertical flow of oxygen from such lance onto the hot metal 14, it being noted that as the oxygen is ignited, burnt lime additions, and in some instances fluorspar, are made for the purpose of producing a slag layer 16 in an amount ranging from about 150 to 300 pounds of slag per ton of metal. Burnt lime is preferably used in order to obtain low phosphorus contents, although some fluorspar can be used where it is desired to speed up the formation of slag and thus promote dephosphorization.

The vertical blow with oxygen is preferably accomplished at the central portion of the surface layer of the molten bath so as to maintain the resulting reaction zone in the bath in a substantially localized zone spaced a substantial distance from the refractory lining of the converter 10, which reaction will impart a substantial circulatory movement in the bath to bring those portions of the molten bath remote from the reaction zone into the reaction zone. During the vertical blowing of the metal

bath the temperature of the molten bath can be controlled to maintain a temperature of about 2875° F. to about 2915° F. by adding roll scale or pellets, and, in some instances scrap, to the metal bath.

Usually in effecting the vertical blow of the molten bath the free end of the vertically disposed oxygen lance 12 is maintained at a distance of about 6 to 80 inches above the surface of the slag cover formed on the molten bath, and the oxygen is supplied through the lance at a rate of from 2500 to 5000 cubic feet per minute and under a pressure of from about 120 to about 175 pounds per square inch and preferably about 150 pounds per square inch so that the oxygen penetrates the slag layer 16 and the surface of the molten metal 14 beneath the slag. The oxygen readily reacts with the oxidizable elements in the molten metal, and the oxygen blow is continued until the carbon content of the molten bath is reduced to within the range of 0.06% to 0.20%, at which level sufficient quantities of oxidizable elements remain in the molten bath to be effective as the oxygen blow is continued, as will be described hereinafter, to prevent a pick-up of nitrogen while maintaining the necessary degree of fluidity and effervescence to meet a desired slag-metal equilibrium. The theory of the reactions effected by the direct vertical blow of oxygen is explained in U.S. Patent No. 2,800,631, issued July 23, 1957, to Suess et al.

Preferably, the vertical oxygen blow is maintained until the carbon content of the molten bath is reduced to an amount ranging from 0.08% to 0.10%, such a reduction being accomplished on a 37-ton bath in a time of about 20 minutes. It will be appreciated that the blowing time will vary in accordance with variations in the size of the metal bath to be refined and the amount of oxygen utilized during the vertical blow, but in any event in accordance with this invention such vertical blow is discontinued when the carbon content of the bath has reached a predetermined amount in the range of 0.06% to 0.20% and preferably in the range of 0.08% to 0.10%.

When the carbon content is reduced to within the range described, the vertical blow of oxygen is discontinued and the vertical lance 12 is removed from the converter 10, after which the converter 10 is tilted about its axis 18 to an angle away from the vertical to a position such as shown in FIG. 2. In tilting the converter 10 as described, it will be appreciated that as the metal bath 14 and slag layer 16 move longitudinally along the side wall of the converter, the depth of the bath is decreased while the surface areas of the molten metal 14 and the slag layer 16 thereafter are enlarged, as will be referred to hereinafter, in comparison with such surface areas of the hot metal and slag layer when the converter 10 is in the initial vertical position during the initial vertical blowing period. A submerged lance 20 having an inner diameter of about one inch is then introduced into the molten metal at an angle to the surface thereof to supply oxygen beneath the surface thereof at a pressure of from 60 to 120 pounds per square inch at a distance from the refractory lining of the converter 10. In the case of a 37-ton bath of metal which has had its carbon content reduced to about 0.10% and the bath is at a temperature of about 2900° F., oxygen is supplied to the metal bath through the submerged lance at a pressure of about 90 pounds per square inch, which corresponds to about 695 cubic feet per minute, or 57.3 pounds of oxygen per minute. Under such conditions an oxygen blow for about 17 minutes is effective to reduce the carbon content to about 0.02% without increasing the nitrogen content of the metal bath, it being noted that such metal bath will have a nitrogen content in the range of from 0.002% to 0.004%.

By tilting the converter 10 and using an oxygen lance 20 with the end thereof submerged in the metal bath and with the flow of oxygen reduced to below the rate of flow utilized in the vertical blow, it is found that the rate of

reaction is somewhat slower than the rate obtained during the vertical blow, but this is advantageous in that the degree of effervescence is normally lower as the lower carbon contents are approached. Sufficient oxidizable elements still remain in the metal bath at the beginning of the submerged lance blow to have definite reactions in the bath, such reactions of the oxygen with the oxidizable elements being at a zone more widely distributed than with the vertical blow and being at a slower rate than is obtained during the vertical blow while being maintained a sufficient distance from the refractory lining of the converter 10 so as to prevent damage to such lining. Since the converter 10 is tilted to in effect provide a more shallow bath having a larger surface area during the submerged lance blow, the reaction products resulting from the reaction of the oxygen with the oxidizable elements have a relatively shorter distance to travel to the slag cover, and the larger surface area of the bath, together with the decrease in depth thereof, permits a more rapid rise of slag inclusions from the metal upwards into the slag cover. Since the lance 20 is submerged in the metal bath, it will be appreciated that the continued flow of oxygen into the bath during the period of slower reaction will be accomplished without any danger of air being entrained therewith or entrapped in the metal bath with the result that the refined metal bath is substantially free of nitrogen, the resulting nitrogen content being, in all cases, less than 0.004%.

As in the case of the vertical blow utilized for effecting the initial reduction of carbon in the metal bath, it will be appreciated that the blowing time utilizing the submerged lance will also vary in accordance with variations in the size of the metal bath and the amount of oxygen utilized during the submerged lance blow to effectively reduce the carbon content to a predetermined amount below 0.035%. In any event, the flow of oxygen through the submerged lance 20 is at a rate lower than the flow rate during the vertical oxygen blow in order to slow down the reaction in the metal bath so as to permit slag inclusions to rise therefrom to the slag cover. The heat of the metal bath is maintained by the reactions during such reduction of carbon so that it is possible to maintain a temperature in the molten bath of 2900° F., plus or minus 30°.

After the bath of metal has been refined as previously described so as to have a carbon content of less than 0.035%, the refined metal can be alloyed with various alloying elements, or, where it is desired to have an extremely pure iron, such refined metal can be poured from the converter through suitable ladles into ingot molds. In the case of the production of silicon steel, the converter 10 containing the refined metal is tilted about its tilting axis 18 to a position where the refined metal is poured through the tapping hole 22 into a receiving ladle (not shown) or is poured therefrom through a series of ladles where predetermined amounts of ferro-silicon and ferro-manganese are added to obtain the desired silicon and manganese analysis. Where the refined metal is poured progressively through a series of ladles, it is to be understood that only a portion of the required ferro-silicon and ferro-manganese may be added in the first receiving ladle, with the additional required amounts of alloying materials being added during the subsequent reladling cycles.

With respect to alloying refined metal to produce silicon iron alloy having predetermined amounts of silicon and manganese, I have utilized a novel and advantageous procedure consisting of tipping the converter 10 and decanting the slag layer from the bath contained therein, after which predetermined amounts of ferro-silicon and ferro-manganese are added to the refined metal bath while the bath is still in the converter. After such additions are made, the converter is rocked about its tilting axis 18 with the result that a much more positive mixing is obtained, thus giving the resulting steel a more uniform analysis when such steel is solidified. Since it will be diffi-

cult to decant the slag 100%, it is best to cover the metal bath in the converter with a quantity of burnt lime in order to prevent reversion of any impurities from the original slag which might have remained in the converter.

The amount of such ferro-silicon and ferro-manganese additions that are required to be made either directly to the molten metal in the converter or in the receiving ladle or ladles to impart predetermined silicon and manganese contents to the resulting alloy can be readily ascertained since the manganese is frequently sampled as the carbon content is being reduced, and a quick analysis of such samples of refined metal will give, not only the carbon content, but also the silicon and manganese contents of such refined metal. Thus, depending upon the results of such analysis, sufficient quantities of ferro-silicon and ferro-manganese are utilized to produce a silicon content of from 2.5 to 4% and preferably 2.9 to 3.4%, and a manganese content of from 0.035 to 0.10% in the resulting metal. Regardless of whether the ferro-silicon and ferro-manganese are added in the converter or in the receiving ladles, as soon as the refined metal is alloyed with such predetermined quantities of silicon and manganese the resulting metal composition is poured in accordance with standard mill practice into ingot molds to produce ingots of predetermined shape and size as required for later mill processing.

The silicon iron metal ingots produced from the refined metal described hereinbefore will have an analysis in the general range given hereinbefore in Table I, it being appreciated that the copper, nickel and tin present in the resulting alloy will depend upon the contents of such elements in the scrap metal utilized during the refining process. Since the resulting ingots are free of inclusions that would suppress secondary grain growth, such ingots or slabs or hot bands formed therefrom can be readily processed into grain oriented silicon steel strip by utilizing the processes taught in the hereinbefore identified Goss patents and the Littmann et al. patent or the Crede et al. patent. Such grain oriented silicon steel strip of 14 mil gauge will have a watt loss at 15 kilogausses of 60 cycles per second of less than .660 watt per pound and a permeability at 10 oersteds of about 18,000.

The low carbon refined iron and silicon iron alloy steel produced in accordance with this invention are more highly refined metals than can be produced in accordance with the LD process as known to the industry. In the case of silicon iron alloy steel produced in accordance with this invention, such steel compares favorably with silicon iron alloy steel produced heretofore by the open hearth practice, but has the advantage that considerable economies are effected in the production of such steel since a considerable amount of time is saved in producing the ultimate ingot over the time required by the open hearth practice. This invention can be readily practiced by those skilled in the trade, for the rates of flow of oxygen and time thereof, as well as the maintenance of the heat balance in the metal being refined for any given size converter and a given bath therein, can be readily calculated.

I claim:

1. A method of refining molten iron which comprises the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on said molten iron, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof to effect a reaction of the oxygen with said bath so as to effect the oxidation of carbon and the oxidizable impurities of said bath, continuing said vertical blowing to reduce the carbon content of said molten iron to within the range of 0.06 to 0.20%, interrupting the flow of oxygen through

the vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface area of the molten iron and slag cover contained therein, inserting a submergible lance through the slag cover into the molten iron, delivering oxygen through the submerged lance into the molten iron at an angle away from the vertical and at a rate of flow less than said vertical flow so as to continue the oxygen reaction in the molten iron beneath the slag cover at a rate slower than the reaction produced by said vertical blowing, and continuing said submerged lance blowing to reduce the carbon content of said molten iron to less than 0.035% and to produce an extremely pure molten iron, said submerged lance blowing being effected without entraining air with the oxygen into the molten iron to thereby prevent nitrogen pickup in the molten iron.

2. A method of refining molten iron which comprises the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on said molten iron, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof to effect a reaction of the oxygen with said bath so as to effect the oxidation of carbon and the oxidizable impurities of said bath in a localized reaction zone and impart a circulatory movement in the bath to bring those portions of the molten bath remote from the reaction zone into the reaction zone, said vertical blowing of oxygen entraining a portion of said slag cover into said molten iron to form an emulsion therein, continuing said vertical blowing to reduce the carbon content of said molten iron containing the emulsion to within the range of 0.06% to 0.20%, interrupting the flow of oxygen through the vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface area of the molten iron and slag cover contained therein, inserting a submergible lance through the slag cover into the molten iron containing the emulsion of slag therein and delivering oxygen therethrough into the molten iron at an angle away from the vertical and at a rate of flow less than said vertical flow so as to continue the oxygen reaction in a localized zone beneath the slag cover at a rate slower than the reaction produced by said vertical blowing to thereby permit the slag of the emulsion to rise from the molten iron to the slag cover, continuing said submerged lance blowing to reduce the carbon content of said molten iron to less than 0.035% as the slag of the emulsion rises to the slag cover to produce an extremely pure molten iron, said submerged lance blowing being effected without entraining air with the oxygen into the molten iron to thereby prevent nitrogen pickup in the molten iron, and removing the slag and the refined molten iron selectively from said vessel.

3. A method of producing a refined iron base metal composition which comprises the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted about an axis through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on said molten iron, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at the central portion thereof to effect a reaction of the oxygen with said bath so as to effect the oxidation of carbon and the oxidizable impurities of said bath, said vertical blowing of oxygen entraining a portion of said slag cover into said molten iron to form an emulsion

therein, continuing said vertical blowing to reduce the carbon content of said molten iron containing the emulsion to within the range of 0.06% to 0.20%, interrupting the flow of oxygen through the vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface area of the molten iron and slag cover contained therein, inserting a submergible lance through the slag cover into the molten iron containing the emulsion of slag therein and delivering oxygen therethrough into the molten iron at an angle away from the vertical and at a rate of flow less than said vertical flow so as to continue the oxygen reaction beneath the slag cover at a rate slower than the reaction produced by said vertical blowing to thereby permit the slag of the emulsion to rise from the molten iron to the slag cover, continuing said submerged lance blowing to reduce the carbon content of said molten iron to less than 0.035% as the slag of the emulsion rises to the slag cover to produce an extremely pure molten iron, said submerged lance blowing being effected without entraining air with the oxygen into the molten iron to thereby prevent nitrogen pickup in the molten iron, decanting the slag from the refined iron in said vessel, adding predetermined alloying elements to the refined molten iron in the vessel, rocking the vessel about its tilting axis to effectively distribute the alloying elements substantially uniformly throughout the melt, and pouring the refined metal containing said predetermined alloying elements from said vessel.

4. A method of producing silicon iron alloy capable of being processed into grain oriented silicon iron strip and sheet comprising the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted about an axis through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on said molten iron, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof to effect a reaction of the oxygen with said bath so as to effect the oxidation of carbon and the oxidizable impurities of said bath, continuing said vertical blowing to reduce the carbon content of said molten iron to within the range of 0.06% to 0.20%, interrupting the flow of oxygen through the vertical lance, tilting the vessel about its axis to a predetermined angle away from the vertical to enlarge the surface area of the molten iron and slag cover contained therein, inserting a submergible lance through the slag cover into the molten iron, delivering oxygen through the submerged lance into the molten iron at an angle away from the vertical and at a rate of flow less than said vertical flow so as to continue the oxygen reaction in the molten iron beneath the slag cover at a rate slower than the reaction produced by said vertical blowing, continuing said submerged lance blowing to reduce the carbon content of said molten iron to less than 0.035% and to produce an extremely pure molten iron, said submerged lance blowing being effected without entraining air with the oxygen into the molten iron to thereby prevent nitrogen pickup in the molten iron, decanting the slag from the refined molten iron in the vessel, adding predetermined amounts of ferro-silicon and ferro-manganese to the refined molten iron in the vessel to impart thereto a silicon content of from 2.5 to 4.0% and a manganese content of from 0.035 to 0.10%, rocking the vessel about its tilting axis to distribute the silicon and manganese contents substantially uniformly throughout the melt, and pouring the resulting molten silicon iron into a receptacle.

5. A method of producing silicon iron ingots capable of being processed into grain oriented silicon iron strip and sheet comprising the steps of, preparing a bath of

molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted about an axis through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on the molten metal bath, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof to effect an oxidation of the impurities of the bath and to reduce the carbon content thereof, continuing said vertical blowing until the carbon content is reduced to within the range of 0.06% to 0.20%, interrupting the flow of oxygen and removing said vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface areas of the bath and slag cover contained therein, inserting a submergible lance through the slag cover into the molten metal bath to deliver oxygen to the molten metal bath at an angle away from the vertical, the flow of oxygen through the submergible lance being at a rate less than the rate of flow through the vertical lance to impart a slower reaction with the oxidizable impurities in the bath and permit slag inclusions to rise therefrom to the slag cover, continuing the submerged oxygen flow until the carbon content of the metal bath is reduced to not more than 0.035% and an extremely pure metal bath is produced, selectively removing the pure metal bath and slag from the vessel, allowing silicon and manganese with the refined metal to impart thereto a silicon content of from 2.90 to 3.40% and a manganese content of from 0.035 to 0.10% while maintaining the carbon content at not more than 0.035%, and pouring the resulting molten silicon iron into ingot molds.

6. A method of producing silicon iron ingots capable of being processed into grain oriented silicon iron strip and sheet comprising the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted through a plurality of positions from the vertical, inserting a lance vertically within the vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on the molten metal bath, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof while the vessel is maintained in a vertical position to effect an oxidation of the impurities of the bath and to reduce the carbon content thereof, continuing said vertical blowing until the carbon content is reduced to within the range of 0.06% to 0.20%, interrupting the flow of oxygen and removing said vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface areas of the bath and slag cover therein, inserting a submergible lance through the slag cover into the molten metal bath to deliver oxygen into the molten metal bath at an angle away from the vertical, the flow of oxygen through the submergible lance being at a rate less than the rate of flow through the vertical lance to impart a slower reaction with the oxidizable impurities in the bath and permit slag inclusions to rise therefrom to the slag cover, continuing the submerged oxygen flow until the carbon content of the metal bath is reduced to not more than 0.035% and an extremely pure metal bath is produced, pouring the pure metal bath into a ladle containing sufficient ferro-silicon and ferro-manganese to impart to the metal a silicon content of from 2.90 to 3.40% and a manganese content of from 0.035 to 0.10% while maintaining the carbon content at not more than 0.035%, and pouring the resulting molten silicon iron into ingot molds.

7. A method of producing silicon iron ingots capable of being processed into grain oriented silicon iron strip and sheet comprising the steps of, preparing a bath of

molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted through a plurality of positions from the vertical, inserting a lance vertically within the vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on the molten metal bath, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof while the vessel is maintained in a vertical position to effect an oxidation of the impurities of the bath and to reduce the carbon content thereof, continuing said vertical blowing until the carbon content is reduced to within the range of 0.06% to 0.20%, interrupting the flow of oxygen and removing said vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface areas of the bath and slag cover therein, inserting a submergible lance through the slag cover into the molten metal bath to deliver oxygen into the molten metal bath at an angle away from the vertical, the flow of oxygen through the submergible lance being at a rate less than the rate of flow through the vertical lance to impart a slower reaction with the oxidizable impurities in the bath and permit slag inclusions to rise therefrom to the slag cover, continuing the submerged oxygen flow until the carbon content of the metal bath is reduced to not more than 0.035% and an extremely pure metal bath is produced, pouring the refined metal from the vessel progressively through a plurality of ladles, each of which contains ferro-silicon and ferro-manganese in predetermined amounts to impart to the resulting molten metal a silicon content of from 2.50 to 4.0% and a manganese content of from 0.035 to 0.10%, and pouring the resulting molten silicon iron into ingot molds.

8. A method of producing silicon iron ingots capable of being processed into grain oriented silicon iron strip and sheet comprising the steps of, preparing a bath of molten impure iron in the presence of a slag in a vertically extending vessel having a refractory lining and disposed to be tilted through a plurality of positions from the vertical, inserting a lance vertically within the vertically extending vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on the molten metal bath, blowing oxygen through said lance at a pressure of from 120 to 175 pounds per square inch vertically downwardly through the slag cover onto and below the surface of the bath at substantially the central portion thereof while the vessel is maintained in a vertical position to effect an oxidation of the impurities of the bath and to reduce the carbon content thereof, continuing said vertical blowing until the carbon content is reduced to within the range of 0.06% to 0.20%, interrupting the flow of oxygen and removing said vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface areas of the bath and slag cover therein, inserting a submergible lance through the slag cover into the molten metal bath to deliver oxygen into the molten metal bath at an angle away from the vertical, the flow of oxygen through the submergible lance being at a rate of from 60 to 120 pounds per square inch to impart a slower reaction with the oxidizable impurities in the bath than that obtained with the vertical blow and to permit slag inclusions to rise therefrom to the slag cover, continuing the submerged oxygen flow until the carbon content of the metal bath is reduced to not more than 0.035% and an extremely pure metal bath is produced, pouring the pure metal bath into at least one ladle containing sufficient ferro-silicon and ferro-manganese to impart to the molten metal a silicon content of from 2.90 to 3.40% and a manganese content of from 0.035 to 0.10% while maintaining the carbon content at not more than 0.035%, and pouring the resulting molten silicon iron into ingot molds.

9. A method of producing silicon iron ingots capable of being processed into grain oriented silicon iron strip

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and sheet comprising the steps of, preparing a bath of molten impure iron in the presence of a slag in a vessel having a refractory lining and disposed to be tilted through a plurality of positions including a vertical position, positioning the vessel in a vertical position, inserting a lance vertically within the vessel with the lower end of the lance terminating from 6 to 80 inches above the slag cover on the molten metal bath, blowing oxygen through the vertical lance vertically downwardly through the slag cover onto and below the surface of the bath at the central portion thereof while the vessel is maintained in a vertical position to effect a reaction of the oxygen with a portion of the iron and with the oxidizable impurities of the bath in a localized reaction zone spaced a substantial distance from the refractory lining whereby said reaction imparts a circulatory movement in the bath to bring those portions of the molten metal bath remote from the reaction zone into the reaction zone, said vertical blowing of oxygen entraining a portion of said slag cover into the metal bath to form an emulsion therein, continuing said vertical blowing to reduce the carbon content of said bath containing the emulsion to within the range of 0.6% to 0.20%, interrupting the flow of oxygen through the vertical lance, tilting the vessel to a predetermined angle away from the vertical to enlarge the surface area of the bath and slag contained therein, inserting a submergible lance through the slag cover into the molten metal bath containing the emulsion of slag therein and delivering oxygen therethrough into the molten metal bath at an angle away from the vertical and at a

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rate of flow less than said vertical flow so as to continue the oxygen reaction in a localized zone spaced a substantial distance from the refractory lining of the vessel at a rate slower than the reaction produced by said vertical blowing to thereby permit the slag of the emulsion to rise from the bath to the slag cover while the oxygen effectively reacts with the oxidizable impurities and reduces the carbon content of the molten metal to not more than 0.035% to produce an extremely pure metal bath, removing the slag and pure metal bath selectively from said vessel, and alloying silicon and manganese with the pure metal bath to produce a silicon content therein of from 2.90% to 3.40% and a manganese content therein of from 0.35% to 0.10% while maintaining the carbon content at below 0.035%, and pouring the resultant molten silicon iron into ingot molds.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,030,203

April 17, 1962

Glenn E. Hilliard

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 9, for "or" read -- of --; column 6, line 40, for "of" read -- and --; line 42, for "18,000" read -- 1800 --; column 9, line 29, for "allowing" read -- alloying --; column 10, line 70, for "0.35" read -- 0.035 --; column 11, line 23, for "0.6%" read -- 0.06% --; column 12, line 4, for "recation" read -- reaction --; line 14, for "0.35%" read -- 0.035% --.

Signed and sealed this 23rd day of October 1962.

(SEAL)

Attest:

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