

Dec. 12, 1961

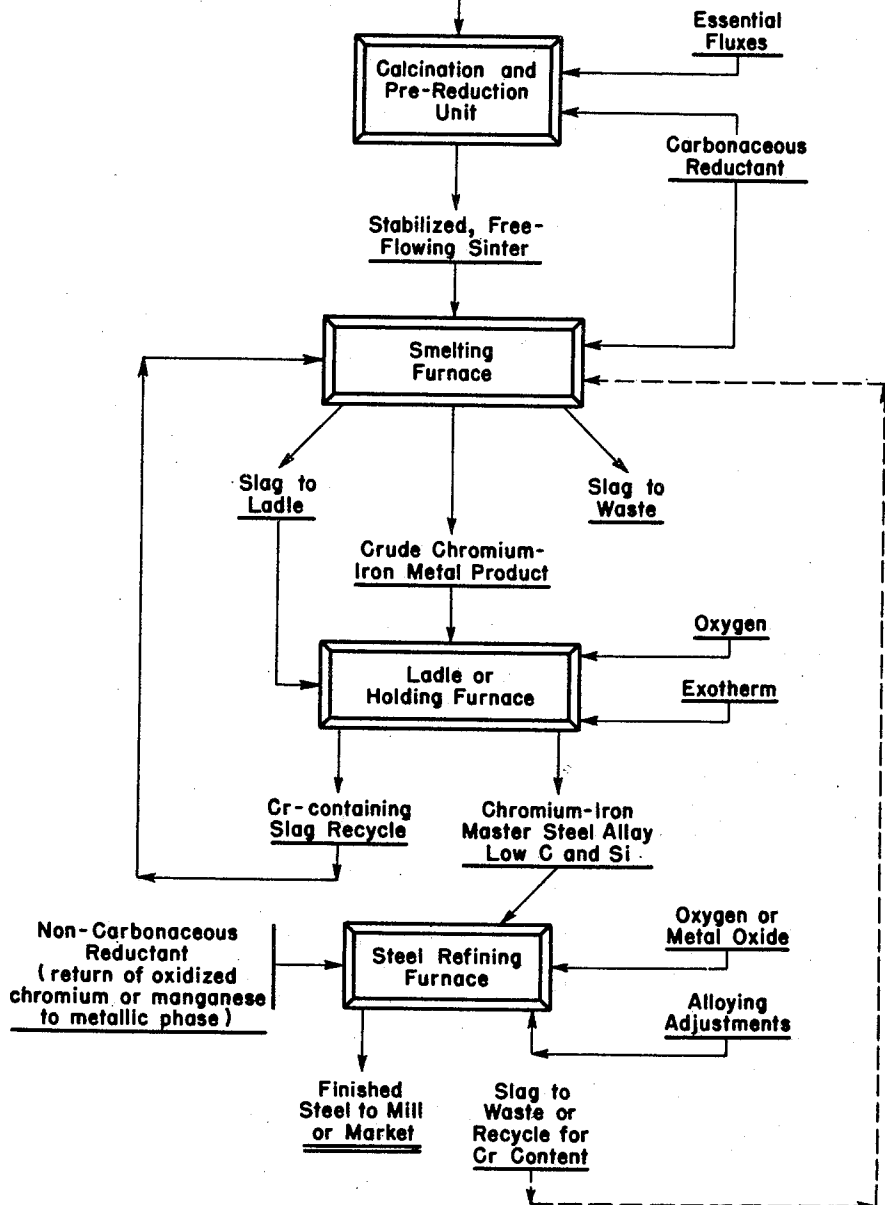
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3,012,875

METALLURGICAL PROCESS

Filed Dec. 4, 1959

Chromite Ore or Concentrate
or
Blended Iron Oxide-Chromite
Reduction Burden



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3,012,875

METALLURGICAL PROCESS

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Filed Dec. 4, 1959, Ser. No. 857,414

10 Claims. (Cl. 75-11)

This invention relates in general to metallurgy and has for its principal object the provision of a new and improved process for producing chrome-iron alloys of controlled silicon-carbon contents and special grades of finished steels directly from chromite ores and concentrates, including conventional high-grade ores, marginal and low-grade chromite ores of chromium-to-iron ratios as low as 0.5 to 1.0, and various physical mixtures or blends of iron oxide- and chromium oxide-bearing materials. Specifically, the invention involves the provision of a unique process for the direct carbothermic reduction of either raw or previously concentrated materials of the general class defined for the production and recovery of valuable medium-carbon chrome-iron master alloys which can be processed to provide a wide variety of finished steels including, by way of illustration, straight ferritic or martensitic chromium steels of the Series 400 and 500 types, austenitic steels of the so-called "Strauss" or Series 300 types, such as the popular 18-8 stainless steel, modified chromium-nickel steels such as the silicon-containing "Rezistal" type of austenitic alloys, low-chromium and chromium-vanadium toolsteels, manganese-chromium steels, and the like.

Heretofore, it has been considered axiomatic that the processing of chromite ores including low chromium-to-iron ratio oxidic reduction burdens should proceed via various beneficiation operations aimed at attaining intermediate products of chromium-to-iron ratios within the range of from 3 to 5 parts chromium to each part iron, namely, products which are amenable to treatment by existing methods for the production of high-chromium (68-72% Cr), low-iron ferrochromium alloys. Materials which are not suited for conversion to chromium base alloys are generally viewed as being unsatisfactory for commercial use, and the majority of the technological developments within this field in recent years have been directed to methods for rendering the abundant low-grade chromites amenable for treatment via techniques developed and adopted by industry in conjunction with the processing of high-grade chromite ores to steelmaking ferroalloys. For example, in copending United States application Serial No. 731,993, which was filed by Marvin J. Udy on April 30, 1958, now Patent No. 2,934,422, granted April 26, 1960, there are described and claimed a series of related processes which are directed to the multi-stage smelting of chromite-bearing materials for the production and recovery of so-called standard grades of ferrochromium. In accordance with the processes of said copending application, a natural chromite ore or concentrate of relatively low Cr:Fe ratio is beneficiated for ultimate use in the production of ferrochromium alloys by an initial carbothermic smelting operation conducted for the selective reduction and removal of excess iron present in the ore or concentrate, with the production and recovery of low-carbon metallic iron of controlled low-chromium content or a high-carbon ferrochromium alloy of off-grade or relatively low-chromium content and a molten slag product of relatively enriched chromium oxide content containing iron in any desired proportion lower than that of the original raw charge material. In essence, in accordance with the process of said copending application, the initial smelting operation is conducted

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to adjust the chrome:iron ratio within the slag to any desired value according to the exact nature of the ferrochrome alloy sought to be recovered within a subsequent smelting operation or operations conducted with the chromium enriched, i.e., iron-degraded, slag recovered from the first stage, while at the same time placing the residual chromium oxide values present in the slag in condition for substantially complete reduction and settling-out or recovery of the metallic chromium from the ultimate waste slag product produced in said subsequent smelting operation or operations.

In processing the residual chrome-enriched slag from the first stage for the production of high-carbon and medium-carbon ferrochromium products, a second smelting operation is required whereas, if the enriched slag is to be processed to low-carbon ferrochromium, two or even three additional stages of smelting are required, depending upon whether the non-carbonaceous reductant necessary for this type of product is produced from the original starting material or simply obtained from an external source.

Significantly, for the most part, the multi-stage nature of such known processes has been considered essential heretofore by reason of the low Cr:Fe ratios of the starting materials and the extreme difficulty encountered in attempting to maintain carbon and silicon controls within any attempted direct or even selective carbothermic reduction type of operation.

It has been postulated that non-carbonaceous reductants such as ferrosilicon or ferrochromium silicon can be employed to maintain carbon specifications within tolerable boundaries, but experience demonstrates that when low-silicon contents are also desired, as would be the case in any steelmaking operation since the silicon content of the melt must be oxidized into the slag before decarburization can be effected, this type of reductant must be employed in deficient amounts, i.e., in quantities less than the stoichiometric requirements of the contained iron oxide and chromium oxide contents of the starting material, with the result that a consequent sacrifice in the yield of metal obtained becomes necessary. Needless to say, such a sacrifice becomes impossible when one is concerned with the marginal and low-grade chrome-iron starting materials.

In order to understand the full significance of the process of my invention, it is essential to understand current industrial practices with respect to the production of stainless steels. Thus, with very few exceptions the production of ferroalloys employed in steelmaking is effected independently of the steelmaking operation, per se, but in any event, the ferroalloy producer devotes considerable cost and effort to deriving the so-called standard alloys of high chromium (68-72% Cr) and low-iron contents, as well as equivalent high-nickel, low-iron alloys for use in the production of Series 300 steels. As explained hereinbefore, much of the expense incidental to the production of these steelmaking alloys exists with respect to the simple procurement of raw materials which are suitably deficient in iron or at least favorably constituted for the elimination of excess iron, but this factor is actually of no basic importance since the steelmaker must ultimately introduce iron into his melt to produce any of the commercially important stainless steels. That is to say, while the ferroalloy producer goes to considerable added effort and expense to provide relatively low-iron alloys of base constitution corresponding to the alloying metals chromium and nickel, for example, the steelmaker's ultimate use of these alloys is predicated upon iron dilution practices which almost invariably reestablish their end-products as iron base alloys.

Considering the fact that the cost of the contained

chromium in low-carbon ferrochromium, for example, currently ranges from about 37 to 41 cents per pound, and the cost of contained nickel in equivalent ferronickel alloys currently ranges from about 60 cents to over one dollar per pound, it becomes abundantly clear why the production of stainless steels by existing methods represents such a costly undertaking. In addition to these initial production costs, it is customary for the steelmaker to oxidize substantial carbon out of the steel melt by means of ore or oxygen which results in oxidation of appreciable chromium into the slag phase. To recover these values following decarburization and refining of the melt, the steelmaker must then use various expensive deoxidizing or reducing agents such as silicon metal, ferrosilicon, aluminum etc. The combined effect of the use of high grade starting material, strict adherence to so-called standard alloys, and the extensive refining and post-refining reduction operations practiced by the steelmaker has brought the most common stainless steels to current price levels within the range of from 350 to 600 dollars per net ton, even in semi-finished slab or billet forms.

In its broadest aspects, the process of my invention is directed to the provision of a unique combined carbothermic reduction and oxidation technique for the treatment of chromite ores or admixed chromite and iron oxide-bearing materials of virtually any chrome-iron ratio to derive a stainless steel master alloy of predetermined iron and chromium contents corresponding substantially to the precise proportions of these metals desired in a particular grade of finished steel. In other aspects, and particularly those pertaining to the utilization of low-chrome-to-iron ratio (0.5 to 3.0Cr to 1.0Fe) starting materials, the invention departs from existing conventions which dictate that these materials must be processed initially to standard grades of ferrochromium, and provides via a single stage of reduction smelting and an inexpensive, mild ladle or furnace refining operation, a low-carbon chromium-iron alloy which may be processed directly within a conventional steel-making furnace to produce virtually any type of finished steel. Common to all aspects of my invention is the utilization of a combined straight carbothermic reduction and subsequent mild oxidation treatment of the resulting metal phase to achieve close carbon and silicon controls with the production of a master iron-chromium alloy suitable for direct treatment via conventional steelmaking techniques, and a chrome-rich slag phase which can be recycled to the carbothermic reduction stage of the process to provide a substantially closed cycle with respect to incoming chromium values.

The process of the invention is based, in part, upon my discovery that chromite ores or mixtures of chromium- and iron-bearing ores of almost any chromium content within the range of from 10-40% Cr may be subjected to direct carbothermic reduction with preservation of substantially the original chromium-iron balance of the incoming ore or blend within the metal phase product recovered from the reduction operation, and that the residual silicon and carbon contents of this metal phase may be readily reduced to low values of silicon and medium carbon specifications (1.5 to 2.5C) by a simple ladle oxidation with oxygen or an oxygen-containing gas. The resulting low-silicon, medium-carbon master alloy containing from 10-40% chromium, or slightly higher, is then supplied to a conventional steel refining furnace, with any alloying additions desired, and subjected to normal alloy melting and decarburization and refining to produce virtually any desired grade of finished steel. The relatively low-volume chrome-rich slag produced in the intermediate oxygen-refining of the master alloy is recycled directly to the smelting furnace to beneficiate the incoming ore or blend of ores with respect to chromium oxide content.

It is believed that the foregoing process measures may be best understood by reference to the following detailed description of specific embodiments of the invention taken

in conjunction with the accompanying drawing, wherein the single figure constitutes a schematic flow diagram or flow sheet illustrating the exact sequence of steps or operations involved in the processing of a typical iron oxide-chromium oxide reduction burden to a finished stainless steel.

In the general practice of the process of my invention, the ore or concentrate or any suitable blend of ores or concentrates is calcined or otherwise treated, initially, to provide a reduction burden of substantially constant composition with respect to labile oxygen, etc., which is thereafter fluxed by the addition of selected base and acid constituents to form a charge capable of producing a relatively high-melting point fluid slag. Alternatively, in accordance with preferred operating technique, the raw ore or blended ores are mixed with the necessary fluxing additions, and the combined mass is then calcined to produce a substantially stabilized reduction burden of predetermined base-acid ratio. In either event, I generally prefer to follow the unique fluxing techniques described in the above-identified U.S. patent to Marvin J. Udy, although the base-acid ratios of the slag systems of the present invention may be constituted anywhere within the range of from one to two-and-one quarter (1.0-2.25) parts by weight base (calculated as MgO and excluding iron oxide) to each part by weight of silica, and entirely satisfactory results are obtained.

The fluxed charge is calcined by heating within any suitable apparatus, such as a rotary kiln, for example, to establish it at the maximum possible temperature for a free-flowing consistency, without overheating to the extent that the charge will form rings within the kiln. Ordinarily, this can be accomplished quite readily by heating the charge to a temperature within the range of from 900 to 1300° C. Of course, the charges can be melted directly within an electric furnace, but I find that the use of kiln with gas, oil, coal or even waste gases from an electric furnace, provides a more economical operation as compared with the use of electrical energy exclusively. Furthermore, I prefer to operate within the successive smelting and refining stages of the process of the invention with molten metal in order to further economize on power consumption by avoiding the necessity for remelting the master alloy. I also find it to be advantageous to practice pre-reduction within the kiln by the direct addition of at least a portion of the carbonaceous reductant to the kiln charge, consistent, of course, with the primary objective of maintaining maximum through-put in the kiln for supplying the electric furnace or equivalent smelting unit on a continuous basis. Prereduction of chromium oxides in the kiln is to be avoided, but I have found that from 33-60% oxygen removal can be effected in the kiln while maintaining good through-put and avoiding any significant reduction of the chromium oxides contained in the reduction burden.

The hot, free-flowing, partially reduced material discharged from the kiln is passed directly into the smelting zone of an electric furnace maintained at a temperature within the range of from 1450-1750° C., together with additional quantities of a carbonaceous reductant in an amount sufficient to effect reduction to the metallic state of the unreduced iron oxide contained in the slag as well as the chromium oxide content of the slag to the extent desired in the master alloy sought to be produced. Preferably, the chrome reduction is continued to provide an excess of chromium metal in the metallic phase product recovered from the smelting chamber, since adjustment of the final chromium-iron ratio in the master alloy can be readily accomplished by passing any excess chromium into the slag phases of the intermediate or final refining operations. In actual practice, I prefer to make the necessary chromium adjustment within the intermediate oxidation stage, since any chromium oxidized into this slag may be returned to the process most conveniently by recycling of the slag to the smelting furnace. Of course, partial

adjustment of the desired chromium-iron ratio can be achieved in each of the oxidation stages, or the chromium can be maintained high in the master alloy supplied to the steel refining furnace, and provision made for recycling this slag to the smelting furnace where its chromium oxide content is adequate to justify reprocessing of the same.

The metal product from the smelting furnace is separated from the major portion of the residual waste slag produced in this stage and is charged to a simple ladle together with a small quantity of covering slag from the smelting furnace. The metal is immediately blown in the ladle with oxygen by use of a simple oxygen lance or equivalent apparatus, to adjust the carbon content to approximately a low medium-grade specification. Quite expectedly, the mild refining required for this adjustment also results in reducing the silicon content of the chromium-iron alloy, usually to values well below the specifications for stainless steels. In addition, the relatively low-volume covering slag maintained on the ladle during the mild decarburization blow is upgraded substantially by chromium oxide entering the slag from the metal product, and this slag is generally recycled to the smelting furnace with from 20 to 25% chromium content.

If necessary or desirable under specific operating conditions, a holding furnace may be employed intermediate the smelting and steel refining stages to effect more complete settling of metallic shot from the residual slag, and to maintain a reservoir of molten master alloy to insure a smooth cycle of operations. In such event, the intermediate oxidation step can be performed directly within the holding furnace in lieu of the ladle, following settling, and ultimate removal of a portion of the residual waste slag. Such a holding furnace is normally operated under power sufficient to supply radiation losses, and this factor would enhance the action of the oxygen blowing operation. Alternatively, when the intermediate decarburization is effected in a ladle, it is frequently desirable to add a small quantity of an exothermic addition agent, such as ferrosilicon, for example, to supply sufficient heat for an efficient oxygen blowing operation.

While the process of the invention can be practiced in conjunction with any type of smelting equipment, I prefer to employ a covered arc electric furnace operated under conditions of arc-resistance and slag-resistance heating, achieved through the maintenance of relatively short arcs struck to the surface of the molten slag bath, or by positioning the electrode tips in slightly submerged relationship within the slag bath. Incoming charge material is supplied to the surface of the slag bath around the peripheral portions of the furnace chamber in order to maintain the arc zones substantially free of accumulated charge, and heat enters the calcined charge directly from the heated slag bath in contact therewith. Virtually any type of carbonaceous reductant can be employed in the carbothermic reduction smelt, including solid reductants such as bituminous and anthracite coals, lignites or lignite chars, coke breeze, or coke, etc., liquid reductants such as oil, or a gaseous reductant such as a hydrocarbon gas. The solid reducing agent need not be processed to any particular form and, in fact, fines are found to be admirably suited for use in the process.

The master alloy recovered from the ladle or holding furnace is preferably charged directly in molten form to a refining furnace of the electric, open-hearth or converter types, wherein it is blended with any alloying additions, i.e., nickel, ferronickel, manganese, etc., required in accordance with the particular type of steel being produced. The refining or finishing unit is operated in conventional fashion to effect decarburization of the metal and adjustments are made for silicon content, where desired, and the like. Undesirable constituents can be removed during the refining melt or other constituents may be added to obtain the desired final composition. As pointed out hereinbefore, chromium adjustments can be made directly

during the finishing heat by oxidizing any excess chromium into the slag. On the other hand, assuming a correct chromium balance has been obtained in the intermediate blowing stage for the production of the master alloy, it is desirable, following completion of the oxygen decarburization in the finishing furnace, to treat the melt with a small quantity of a non-carbonaceous reducing agent to return to the steel any chromium oxidized into the slag phase during the oxidation reactions. The finished steel is then recovered from the steel furnace and treated by conventional methods for conversion to consumer products.

As will be readily appreciated, in lieu of the alloying additions to the refining furnace, any alloying metals other than the iron and chromium contents of the master alloy required in the finished steel could be carried into the master alloy in whole or in part by direct reduction from an oxidic additive to the original ore or blend of ores charged to the smelting furnace. For example, if a nickel-chromium stainless steel is desired, a high-iron, low-nickel ore such as a nickel laterite could be blended with the chromite ore as a combined source of nickel and iron. The nickel would be reduced initially to form a ferronickel alloy, whereas continued reduction would provide a metal phase product or crude master alloy of combined iron, nickel and chromium contents approximating the ratio of these metals desired in the final steel. Similarly, a ferromanganese ore could be admixed with the initial feed material to supply a self-contained source of manganese alloying metal. The resulting crude alloy would then be subjected to the same treatment as described hereinbefore in connection with the basic iron-chromium master alloy of the invention.

It is believed that the process of the invention will be best understood by reference to the following specific examples illustrating the application of the foregoing principles and procedures to the production of stainless steels from a typical low-grade oxidic starting material:

EXAMPLE I

Master alloy

The equipment utilized in the following operations included a 4.5 ft. diameter by 80 ft. long rotary kiln; a 11 ft. diameter 1000 kva. electric smelting furnace; and a 3-ton electric steel furnace with attendant oxygen supply and necessary auxiliary equipment.

ANALYSES OF ORES

Component	Chromite Ore	Iron Ore
Cr.....	14.6	
Fe.....	13.0	56.73
SiO ₂	19.1	7.54
CaO.....	4.8	0.53
MnO.....	18.5	0.63
Al ₂ O ₃	13.77	2.18
S.....	.006	0.03
P.....	.01	0.02
Loss on ignition.....	5.0	7.12

A blend of the foregoing chromite and iron ores was prepared utilizing 4500 pounds of the chromite ore and 3100 pounds of the iron ore. To this mixture there were added essential fluxes and 950 pounds of a steam coal reductant of 80% fixed carbon content.

The charge was supplied to the rotary kiln and heated therein to produce a free-flowing sinter analyzing 29.1 percent iron (15% metallic Fe), 9.5 percent chromium, and 5% carbon. The sinter, in amount of 7500 pounds, was then transferred to the electric furnace at a temperature of approximately 1150° C. During the smelting cycle 750 pounds of anthracite coal of approximately 80% fixed carbon content was added to the furnace chamber.

The furnace was tapped yielding about 2750 pounds of metal of the following essential analysis:

<i>Metal</i>	<i>Percent</i>
Cr -----	22.3
C -----	2.7
Si -----	0.13
Fe -----	Balance

and 4450 pounds of waste slag of the essential analysis:

<i>Slag</i>	<i>Percent</i>
Fe -----	1.8
Cr -----	4.1
CaO -----	14.1
SiO ₂ -----	24.8
MgO -----	27.1
Al ₂ O ₃ -----	25.0

4050 pounds of the slag was discarded, whereas about 400 pounds was charged to the ladle with the metal recovered from the furnace.

The ladle was blown with a total of 1000 cubic feet of oxygen by means of an oxygen lance to produce 2600 pounds of a master alloy of the following analysis:

<i>Master alloy</i>	<i>Percent</i>
Cr -----	19.1
Si -----	0.03
C -----	1.60
S -----	0.10
P -----	0.035
Fe -----	Balance

In addition, 600 pounds of slag of 20 percent chromium content was recovered from the ladle and recycled to the smelting furnace.

EXAMPLE II

Finished steel

The full quantity of the foregoing master alloy was charged to the refining furnace with a very slight addition of ferromanganese and blown with a total of 1700 cubic feet of oxygen to produce 2500 pounds of a 430 grade stainless steel of the following analysis:

C	Si	S	P	Mn	Cr
0.10	0.69	0.03	0.05	0.31	17.84

Having thus described the subject matter of my invention, what it is desired to secure by Letters Patent is:

1. Process for the production of a master iron-chromium alloy suitable for the direct production of chromium-alloyed steels from a complex reduction burden comprising a major proportion of iron oxide and a minor proportion of chromium oxide that comprises, subjecting said reduction burden to reduction smelting in the presence of a carbonaceous reducing agent in an amount sufficient to effect reduction to the metallic state of substantially all of the iron oxide contained therein and an amount of chromium oxide in excess of the chromium content desired in said final alloyed steel with the production of a crude molten iron-chromium alloy and a residual molten slag product, subjecting said crude molten iron-chromium alloy to a first oxidation treatment with a free-oxygen-containing gas in the presence of a covering layer of said molten slag of sufficient volume to retain chromium values oxidized thereinto from said alloy, thereby effecting partial decarburization and desiliconization of said crude alloy with the production of a molten slag containing chromium oxide and an intermediate iron-chromium alloy of reduced carbon, chromium, and silicon contents, and recycling said chromium oxide-con-

taining slag to said reduction smelting stage, said intermediate alloy being directly refinable to provide a chromium alloyed steel by subjecting the same to a second oxidation treatment, a deoxidation treatment utilizing non-carbonaceous reductants, and necessary alloying adjustments within a steel refining furnace.

2. The process as claimed in claim 1, wherein said alloying adjustments include the addition of nickel, resulting in the production of a nickel-chromium stainless steel.

3. The process as claimed in claim 1, wherein said alloying adjustments include the addition of nickel and manganese, resulting in the production of a nickel-chromium-manganese stainless steel.

4. The process as claimed in claim 1, wherein said complex reduction burden further includes a minor proportion of nickel oxide and there is produced a crude steel alloy containing chromium, nickel and iron in approximate proportions corresponding to the alloy composition desired in a finished stainless steel.

5. The process as claimed in claim 1, wherein said complex reduction burden further includes minor proportions of manganese oxide and nickel oxide and there is produced a crude steel alloy containing chromium, nickel, manganese and iron in approximate proportions corresponding to the alloy composition desired in a finished stainless steel.

6. Process for the production of an iron-chromium alloy for use in the production of stainless steel from a low chromium-iron ratio chromite-bearing charge material that comprises, fluxing said chromite-bearing charge material and thereafter subjecting the fluxed charge to reduction smelting in the presence of a carbonaceous reducing agent in an amount sufficient to effect reduction to the metallic state of substantially all of the iron oxide contained therein and an amount of chromium oxide in excess of the chromium content desired in the final iron-chromium alloy with the production of a crude molten iron-chromium alloy and a residual molten slag product, subjecting said crude molten iron-chromium alloy to a first oxidation treatment with a free-oxygen-containing gas in the presence of a covering layer of said molten slag of sufficient volume to retain chromium values oxidized thereinto from said crude alloy, thereby effecting partial decarburization and desiliconization of the crude alloy with the production of an intermediate iron-chromium alloy of reduced carbon, chromium, and silicon contents and a molten slag product containing excess chromium values oxidized out of said crude iron-chromium alloy under action of said free-oxygen-containing gas, separating said intermediate iron-chromium alloy from said chromium-oxide bearing slag, and recycling said slag to the reduction smelting stage, said intermediate alloy being directly refinable to provide stainless steel by a second oxidation treatment, a deoxidation treatment utilizing non-carbonaceous reductant, and necessary alloying adjustments within a steel refining furnace.

7. Process for the production of an iron-chromium master alloy useful in the production of finished steel from individual ores including (I) a low-grade chromite ore, and (II) an iron oxide-bearing ore, that comprises blending said individual ores in respective proportions to provide a mixed oxidic reduction burden containing iron and chromium in approximate proportions equivalent to the iron-chromium content desired in said finished steel, fluxing said mixed reduction burden and thereafter subjecting the same to reduction smelting within an electric furnace in the presence of a carbonaceous reducing agent in an amount sufficient to effect reduction to the metallic state of substantially all of the iron oxide contained therein and an amount of chromium oxide in excess of the chromium content desired in said finished steel with the production of a crude molten iron-chromium alloy and a residual molten slag product, subjecting said crude molten iron-chromium alloy to a first oxidation treatment with

a free-oxygen-containing gas in the presence of a covering layer of said molten slag of sufficient volume to retain chromium values oxidized therein from said crude alloy, thereby effecting partial decarburization and desiliconization of said crude alloy with the production of a molten slag product containing excess chromium values oxidized out of said crude iron-chromium alloy under action of said free-oxygen-containing gas and an intermediate iron-chromium alloy of reduced carbon, chromium, and silicon contents containing iron and chromium in approximate proportions corresponding to the alloy composition desired in said finished steel, and recycling said chromium oxide containing slag to the reduction smelting furnace, said intermediate alloy being directly refinable to provide said finished steel by means of a second oxidation treatment, a deoxidation treatment utilizing non-carbonaceous reductants, and necessary alloying adjustments.

8. Process for the production of chromium alloyed steel from a complex reduction burden comprising a major proportion of iron oxide and a minor proportion of chromium oxide that comprises subjecting said reduction burden to reduction smelting in the presence of a carbonaceous reducing agent in an amount sufficient to effect reduction to the metallic state of substantially all the iron oxide contained therein and an amount of chromium oxide in excess of the chromium content desired in the final steel with the production of a crude molten iron-chromium alloy and a residual molten slag product, subjecting said crude molten iron-chromium alloy to a first oxidation treatment with a free-oxygen-containing gas in the presence of a covering layer of said molten slag of sufficient volume to retain chromium values oxidized therein to effect partial decarburization and desiliconization of the crude alloy with the production of an intermediate iron-chromium alloy of reduced carbon, chromium, and silicon contents and a molten slag product containing chromium oxide, separating said chromium oxide slag from said intermediate iron-chromium alloy, recycling said slag to the reduction smelting stage, transferring said intermediate alloy to a refining furnace, and subjecting said intermediate alloy to a second oxidation treatment, a deoxidation treatment utilizing non-carbonaceous reductants, and necessary alloying adjustments to effect the production and recovery of a chromium-alloyed steel.

9. The process as claimed in claim 8, wherein said iron-chromium alloy is alloyed with nickel within said refining furnace for the production and recovery of a nickel-chromium stainless steel.

10. Process for the production of finished steel from individual ores including—(I) a low-grade chromite ore, and (II) an iron oxide-bearing ore, that comprises, blending said individual ores in respective proportions to provide a mixed oxidic reduction burden containing iron and chromium in approximate proportions equivalent to the iron-chromium content desired in said finished steel, fluxing said mixed reduction burden and thereafter subjecting the same to reduction smelting within an electric furnace in the presence of a carbonaceous reducing agent in an amount sufficient to effect reduction to the metallic state of substantially all the iron oxide contained therein and an amount of chromium oxide in excess of the chromium content desired in said finished steel with the production of a crude molten iron-chromium alloy and a residual molten slag product, subjecting said crude molten iron-chromium alloy to a first oxidation treatment with a free-oxygen-containing gas in the presence of a covering layer of said molten slag of sufficient volume to retain chromium values oxidized therein to effect partial decarburization and desiliconization of said crude alloy with the production of an intermediate iron-chromium alloy of reduced carbon, chromium, and silicon contents and a molten slag containing chromium oxide, separating said chromium oxide slag from said iron-chromium alloy, recycling said slag to the reduction smelting furnace, transferring said intermediate alloy to a refining furnace, and subjecting said intermediate alloy to a second oxidation treatment, a deoxidation treatment, and necessary alloying adjustments to effect the production and recovery of a finished steel.

References Cited in the file of this patent

UNITED STATES PATENTS

1,586,592	Wild	June 1, 1926
1,793,153	Becket et al.	Feb. 17, 1931
1,901,367	Gustafsson	Mar. 14, 1933
2,098,176	Udy	Nov. 2, 1937
2,109,122	Udy	Feb. 22, 1938
2,430,117	Feild	Nov. 4, 1947
2,546,340	Hilty	Mar. 27, 1951
2,845,342	Udy	July 29, 1958
2,934,422	Udy	Apr. 26, 1960

OTHER REFERENCES

Journal of Metals, February 1949, pages 91-95 relied on.