

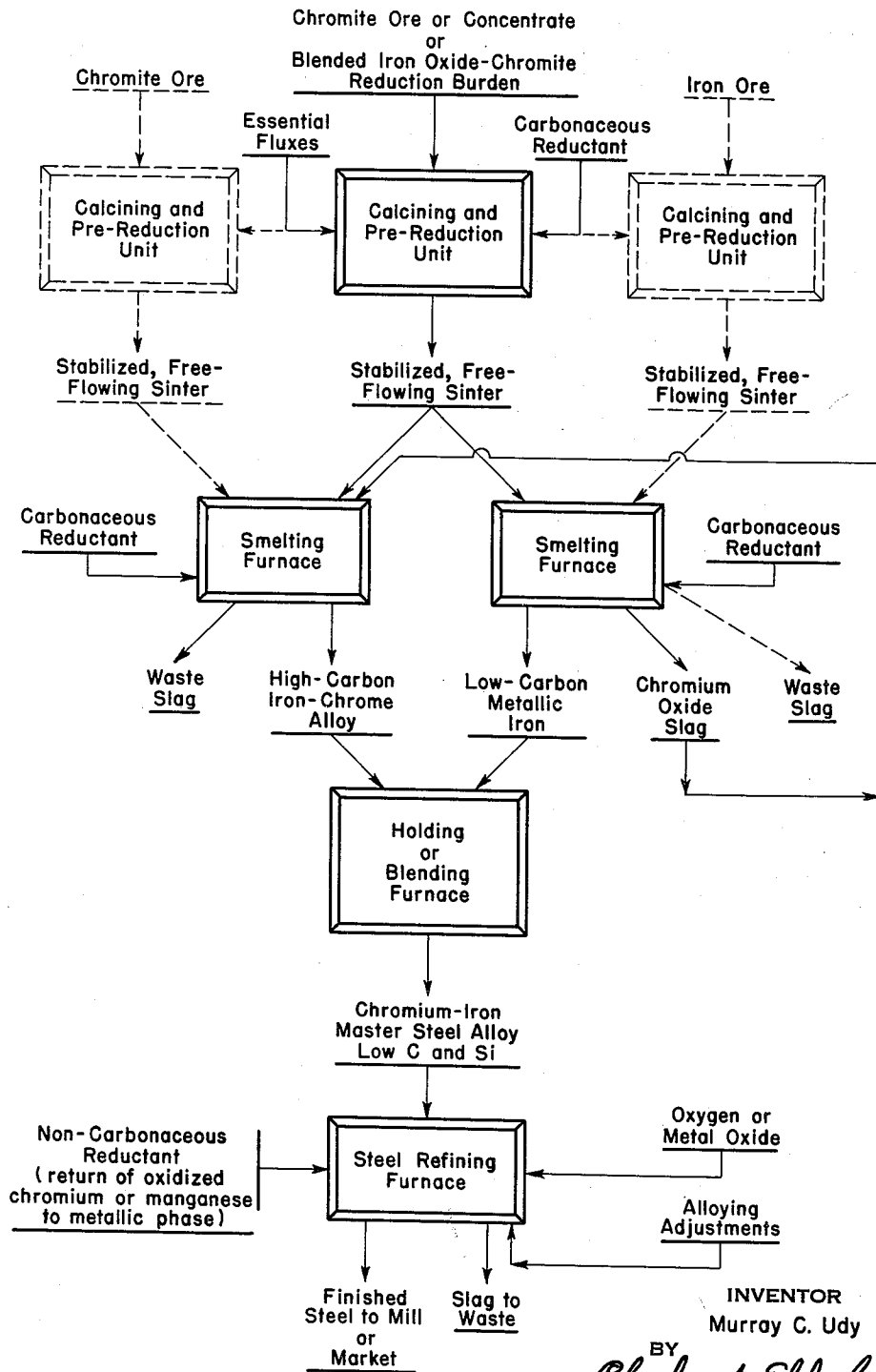
May 30, 1961

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2,986,459

METALLURGICAL PROCESS

Filed Dec. 4, 1959



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2,986,459

METALLURGICAL PROCESS

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Filed Dec. 4, 1959, Ser. No. 857,293

9 Claims. (Cl. 75—40)

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 as shown by the accompanying flow sheet. Specifically, the invention involves the provision of a unique carbothermic reduction of either raw or previously concentrated materials of the general class defined for the production and recovery of valuable low-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 nickel-chromium stainless 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.

The accompanying flow sheet shows various modifications of the invention.

Heretofore, it has been considered axiomatic that the processing of chromite ores and particularly low chromium-to-iron ratio oxidic reduction burdens should proceed via various preliminary 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 ferro-chromium 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 technological developments within this field in recent years have been directed to methods for rendering the 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 Number 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 ferro-

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chromium 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 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 most 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, economically, when one is concerned with the marginal or 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 (67-72% 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 steelmakers' ultimate use of these alloys is predicated upon iron dilution practices which almost invariably re-establish 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 de-oxidizing or reducing agents such as silicon metal, ferro-silicon, aluminum, etc. The combined effect of the use of high-grade starting materials, 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.

It is its broadest aspect, the process of my invention is directed to the provision of a unique tandem stage reduction technique for the treatment of chromite ores or admixed chromite and iron oxide-bearing materials of virtually any chrome-iron ratio to derive a low-carbon stainless steel master alloy of predetermined iron and chromium contents corresponding substantially to the precise proportion of these metals desired in a particular grade of finished steel. In other aspects, and particularly those pertaining to the utilization of extremely low chrome-to-iron ratio 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 tandem reduction smelting arrangement a chromium-iron alloy which may be processed directly within a conventional steelmaking furnace to produce virtually any type of finished steel. Common to all aspects of my invention is the utilization of a unique tandem reduction technique in which a portion of a combined oxidic reduction burden of chromium and iron is subjected to carbothermic reduction to derive an iron-chromium alloy of relatively high-carbon content, whereas the remainder of said reduction burden is simultaneously subjected to carbothermic reduction to derive metallic iron of low-carbon content and a chrome-rich slag for recycle to the iron-chromium alloy-production stage of the tandem reduction cycle. The metallic products of the two furnaces are then recombined in molten form to provide a relatively low-carbon master alloy of iron and chromium which may be processed directly by standard procedure or refining to produce stainless steel of any desired composition.

Essentially, the process of the invention is based, at least in part, on the observation that whereas carbon control is difficult to achieve under conditions involving the simultaneous direct reduction of both chromium oxide and iron oxide and generally necessitates sacrificing a portion of the total available chromium to the slag phase, carbon control to extremely low values can be readily maintained in the selective reduction of iron only from such a mixed oxidic reduction burden. In accordance with a preferred process of the invention, the aforementioned phenomena are utilized to permit maximum chromium reduction with iron from one fraction of a mixed chromium oxide-iron oxide reduction burden of natural or synthetic (blended) origin, without regard to carbon contamination of the resulting iron-chromium product produced, while the remainder of the mixed reduction burden is

subjected to selective carbothermic reduction to produce low-carbon metallic iron or semi-steel. The metallic products of the tandem direct and selective reduction operations are then recombined in proper proportions to yield a controlled carbon content master alloy of chromium and iron ratio approximately equivalent to the precise proportions desired in the final steel product, namely, alloys ranging from 60-90 percent iron and 10-40 percent chromium. The reconstituted master alloy requires only mild refining and alloying additions, as desired, to yield virtually any grade of finished steel. To provide a balanced, closed system with respect to total incoming chromium values, the chromium-rich slag produced in the iron production phase of the tandem reduction operation is recycled, preferably in molten form, to the direct reduction stage for addition to its fraction in the production of further quantities of the high-carbon iron-chromium alloy.

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 or corrosion-resistant steel.

In the practice of the process of my invention, a chromite ore or concentrate, or such a material blended in any desired proportion with an iron oxide-bearing material, is calcined or otherwise treated, initially, to provide a mixed reduction burden of substantially constant composition with respect to water, 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 blend of ores is 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 prefer to follow the unique fluxing techniques described in the above-mentioned U.S. Patent to Marvin J. Udy, although the base-acid ratios of the slag systems of the present invention may be constituted at optimum values 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 1100° to 1300° C. Of course, the split charges can be melted directly within the tandem electric furnaces, but I find that the use of a 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 charge from a preceding stage in order to further economize on power consumption by avoiding the necessity for remelting these materials. I also find it to be advantageous to practice some pre-reduction within the kiln by the direct addition of a portion of the overall carbonaceous reductant to the kiln charge consistent, of course, with the primary objective of maintaining maximum through-put in the kiln for supplying the tandem electric furnaces or equivalent smelting units on a continuous basis. Pre-reduction of chromium oxides in the kiln is to be avoided,

but it is found that from 33-60% oxygen removal can be effected in the kiln while maintaining good throughput and avoiding any significant reduction of the chromium oxides contained in a reduction burden.

The hot, free-flowing partially reduced material discharged from the kiln is subdivided into two approximately equal-weight fractions. This subdivision and, in turn, the respective loads on the tandem furnaces can be regulated in accordance with the chrome-iron ratio of the original material, as modified to the extent that any blending is practiced in the formation of the iron oxide-chromium oxide charge material.

The fraction to be treated by direct and substantially total reduction for the production of the iron-chrome alloy is charged to the smelting zone of one of the tandem electric furnaces 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 all of the chromium oxide and iron oxide contained therein. The resulting metal product will have a chromium-iron ratio corresponding to that of the original ore or blended ores, but upgraded with respect to chromium content to any desired extent by reason of the additional chromium oxide values recycled from the tandem furnace operating on the selective reduction cycle for low-carbon iron. In view of the fact that the former furnace is operated for maximum chromium recovery in the metal phase, the carbon content in the iron-chrome alloy recovered will normally range upwards to 6 percent. Where justified for any specific starting material, a lower carbon content can be achieved in the iron-chrome alloy by leaving a portion of the chromium oxide content in the residual waste slag produced in this furnace. In general, however, by reasons of the ease of carbon control attained through practice of the dilution technique of the invention, I prefer to effect maximum chromium reduction in this phase of the tandem operation.

The remaining fraction of the kiln sinter is supplied to the smelting zone of the second tandem furnace, which is also maintained at a temperature within the range of from 1450-1750° C., together with a controlled quantity of carbonaceous reductant sufficient to effect the selective reduction to the metallic state of the major portion of the iron contained therein. In this connection, it is to be noted that in a reduction operation of the class described, the metallic phase product can be maintained substantially free of carbon contamination until the residual iron in the slag phase reaches a level equivalent to approximately 6-8% Fe. Thereafter, continued reduction of the charge under action of a carbonaceous reducing agent results in slight gradual carbon contamination of the metal until a residual level of approximately 3-4 percent iron is reached in the slag phase, but attempted carbonaceous reduction beyond this 3-4 percent iron residue results in rapid carbon contamination of the metal. Within the range 3-8 percent iron unreduced in the slag, it is generally found that the major portion of the chromium is likewise retained in oxide form within the slag. At the upper limits of this range, namely, 6-8 percent residual iron, it is possible to achieve carbon control within the range of from 0.2 to 0.5 percent, with a simultaneous low-chromium content within the metallic iron phase product. Of course, provided the full production of the tandem iron furnace is to be utilized for dilution of the carbon content in the high-carbon iron-chrome alloy from the other tandem furnace, it is relatively immaterial whether the iron product also contains a portion of the chromium in metallic form and, under these circumstances, the selective reduction is simply continued to the maximum possible limit consistent with the carbon level desired in the metal phase. On the other hand, it sometimes proves desirable to "bleed" a portion of the total iron production out of the system for marketing or for use in the production of

carbon steel and, under such circumstances, it is equally desirable to maintain a low-chromium content in the output product from the selective reduction or iron tandem furnace. These objectives can be obtained by operating the iron furnace at various residual iron levels within the range from 3 to 8 percent, in that, both the carbon and chromium contents of the iron can be expected to increase as the reduction is carried below the upper limits of this range.

The metallic phase products from the tandem furnaces, or any portion of these products, are brought together in molten form in the precise ratio desired in the final steel product sought to be produced. This blending or carbon dilution operation will generally result in the production of a composite master alloy of carbon content within the range of from 0.3 to 1.5 percent, and a silicon content within the range of from 0.1 to 0.5 percent. Thus, since the high-carbon chromium-iron alloy is diluted to an iron-base alloy, in lieu of the conventional chromium-base alloys presently used in steel making, it is entirely possible to reduce the carbon content in the composite master alloy to medium- and low-carbon values. Preferably, the blending or dilution operation is conducted within an intermediate holding furnace or directly within the steel refining unit of the system.

The master alloy recovered from the holding furnace or formed in situ in a refining furnace of the electric, open-hearth or converter types, 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 grade specifications for the steel produced. 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 initial smelting and blending operations conducted towards 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 noncarbonaceous 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 is treated by conventional working 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 blended-ore fraction charged to the iron-chrome smelting furnace. For example, if a nickel-chromium stainless steel is desired, a nickel-iron or nickel ore could be blended with the chrome-iron fraction charged to the alloy furnace 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 high-carbon alloy of combined iron, nickel and chromium contents for ultimate blending with the low-carbon iron produced in the second tandem furnace. The resulting crude alloy would then be subjected to the same treatment as described hereinbefore in connection with the basic high-carbon iron-chromium alloy component of the invention.

In the operation of the tandem smelting stages of the process of the invention, I prefer to employ a carbonaceous reducing agent such as bituminous or anthracite coals, lignites or lignite chars, coke breeze, or coke, etc. The carbonaceous reductants need not be processed to any

particular form and, in fact, fines are found to be admirably suited for use in the process.

While the process can be practiced in conjunction with any type of smelting equipment, I prefer to employ a covered arc electric furnace operated under conditions of combined 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.

In utilizing the chromium oxide slag from the low-carbon iron furnace to upgrade the original fraction charged to the high-carbon alloy furnace, I prefer to add the slag in molten form directly to the electric furnace, and then add the sinter fraction and reductant necessary for the production of the iron-chromium metal.

It will be readily apparent to any skilled metallurgist that for particular types of chromite charge materials, it may prove beneficial to maintain the chromite and iron ores separate through the tandem reduction phases of the process, bringing the end-products of the two smelting furnaces together for the first time in the blending of the low-carbon master alloy. Thus separate kilns can be utilized to feed one furnace with a sintered chromite ore and the other with a sintered iron ore, the first furnace operating on total direct reduction for the production of a high-carbon chrome-iron alloy, with the second furnace also operating on direct reduction for the production of low-carbon iron or semi-steel. These products would then be blended to dilute the carbon content of the alloy with the production of the desired low-carbon master alloy. Under these conditions of operation, it becomes possible to eliminate the necessity for recycling the slag from the iron furnace to the alloy furnace. The exact sequence of steps involved in this type of operation has been indicated by the dotted line showing contained on the flowsheet.

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
Charge analyses

Component	Iron Ore, percent	Chromite Concentrate, percent
Cr		19.6
Fe	57.31	17.5
SiO ₂	10.64	12.28
CaO	0.40	3.48
MgO	0.13	14.05
Al ₂ O ₃	1.77	15.21
Loss on Ignition	5.15	4.5

A chromite concentrate of the foregoing analysis, in amount 4540 pounds, was blended thoroughly with 4280 pounds of iron ore of the foregoing analysis and charged to a rotary kiln together with 1100 pounds of coal of about 70 percent fixed carbon content. The charge was preheated and prereduced in the kiln to provide a free-flowing sinter at 2250° F. which analyzed 11.2 percent chromium and 33.3 percent iron, with a carbon content of about 5.0%.

This sinter, in total amount 7910 pounds, was divided into two separate charges of 2710 pounds and 5200 pounds, respectively.

The former charge (2710 lbs.) was supplied to an arc electric furnace together with 2300 pounds of a recycled residual slag product recovered from the tandem iron furnace analyzing 12.1 percent chromium and 1.0 percent iron. A total of 290 pounds of coal of 70 percent fixed carbon content was added to the furnace burden, and smelting was completed to produce separate metallic and slag phases of the following respective essential analyses:

Metal (1785 lbs.):	Percent
Cr	31.1
C	6.0
Si	1.0
Fe	Bal.
Slag (2848 lbs.):	
Cr	1.0
Fe	1.2

The second fraction of the kiln discharge, weighing 5200 pounds, was smelted in a second arc electric furnace in the presence of 250 pounds of coal of 70 percent fixed carbon content to produce 2460 pounds of iron of 1.0 percent carbon content and a recyclable chromium oxide slag containing about 1.0 percent residual iron.

The 1785 pounds of high-carbon chrome-iron from the first tandem furnace and the 2460 pounds of low-carbon iron from the second tandem furnace were recombined in a steel refining furnace with a lime flux and blown with oxygen to produce 4080 pounds of a standard grade steel containing 19.7 percent chromium and 0.03 percent carbon.

EXAMPLE II

Chromite concentrates of the foregoing analysis, in amount 4500 pounds, 100 pounds of quartz, and 250 pounds of coal of 70 percent fixed carbon content were blended and heated in a rotary kiln to produce 4620 pounds of hot (2250° F.) free-flowing sinter analyzing, 17.1 percent iron and 19.25 percent chromium, with about 5.0 percent carbon. This sinter was supplied to an arc electric furnace and was smelted therein in the presence of 330 pounds of coal (70% F.C.) to produce separate metallic and slag phases of the following respective essential analyses:

Metal (1665 lbs.):	Percent
Cr	52.0
C	6.0
Si	1.0
Fe	Bal.
Slag (2140 lbs.):	
Cr	1.7
Fe	1.0

A second kiln was charged with 4400 pounds of iron ore of the foregoing analysis, 600 pounds of lime, and 900 pounds of coal (70% F.C.). The hot kiln discharge, in amount 4230 pounds, analyzing 57 percent iron and 5 percent carbon, was charged to a second electric furnace together with 290 pounds of coal (70% F.C.) and smelted therein with the production of 2520 pounds of semi-steel of 0.5 percent carbon.

The 1665 pounds of chrome-iron from the first furnace and the 2520 pounds of semi-steel from the second furnace were combined in a steel refining furnace and blown with oxygen to provide 4050 pounds of steel of the following analysis:

	Percent
Cr	20.3
C	0.04
S	0.02
P	0.02
Mn	0.72
Si	0.48

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 alloyed steel from ores of chromium oxide and iron oxide that comprises, subjecting a first ore fraction of mixed chromium and iron oxide contents 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy and a waste slag product, subjecting a second ore fraction containing a predominant proportion of iron oxide to reduction smelting in the presence of a carbonaceous reducing agent in an amount controlled to effect the selective reduction to the metallic state of the major portion of the iron oxide content thereof with the production of low-carbon metallic iron, blending said high-carbon iron-chromium alloy with said low-carbon metallic iron to provide a master alloy of controlled intermediate carbon content, and refining said master alloy as necessary for the production and recovery of a chromium-alloyed steel product.

2. The process as claimed in claim 1, wherein said first ore fraction is a chromite ore and said second ore fraction is an iron ore.

3. The process as claimed in claim 1, wherein said first and second ore fractions are each formed by blending a chromite ore with an iron oxide ore, there being recovered a chromium oxide-containing residual slag from said reduction smelting of the second ore fraction, and said slag is recycled to the reduction smelting operation conducted on said first ore fraction.

4. Process for the production of alloyed steel from a complex material comprising iron oxide and chromium oxide that comprises fluxing said material to form a composite reduction charge, subjecting a first fraction of said composite 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy and a waste slag product, subjecting a second fraction of said composite charge to reduction smelting in the presence of a carbonaceous reducing agent in an amount controlled to effect the selective reduction to the metallic state of the major portion of the iron oxide content thereof with the production of low-carbon metallic iron and a chromium oxide-containing molten slag product, recycling said chromium oxide-containing molten slag to the reduction smelting stage operating on the first fraction of said charge, blending said high-carbon iron-chromium alloy with said low-carbon metallic iron to provide a master iron-chromium alloy of controlled intermediate carbon content, and refining said master alloy as necessary for the production and recovery of a chromium-alloyed steel product.

5. Process for the production of alloyed steel from a complex material comprising iron oxide and chromium oxide that comprises fluxing said material to form a composite reduction charge, subjecting a first fraction of said composite 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy and a waste slag product, subjecting a second fraction of said composite charge to reduction smelting in the presence of a carbonaceous reducing agent in an amount controlled to effect the selective reduction to the metallic state of the major portion of the iron oxide content thereof with the production of low-carbon metallic iron and a chromium oxide-containing molten slag product, recycling said chromium oxide-containing molten slag to the reduction smelting stage operating on the first fraction of said charge, blending said high-carbon

iron-chromium alloy with said low-carbon metallic iron to provide a master iron-chromium alloy of controlled intermediate carbon content, refining said master alloy within a refining furnace in the presence of a non-carbonaceous refining agent for the production and recovery of a chromium-alloyed steel product.

6. The process as claimed in claim 5, wherein said master alloy is subjected to refining within the refining furnace together with a nickel alloying additive for the production and recovery of a nickel-chromium-alloyed steel product.

7. Process for the recovery of iron and chromium in alloyed form from a complex material comprising iron oxide and chromium oxide that comprises fluxing said material to form a composite reduction charge, subjecting a first portion of said composite 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy of predetermined iron-chromium ratio and a waste slag product, subjecting a second portion of said composite charge to reduction smelting in the presence of a carbonaceous reducing agent in an amount controlled to effect the selective reduction to the metallic state of the major portion of the iron oxide content thereof with the production of low-carbon metallic iron and a chromium oxide-containing molten slag product, recycling said chromium oxide-containing molten slag product to the reduction smelting stage operating on said first charge portion, and blending said high-carbon iron-chromium alloy and said low carbon metallic iron to provide an iron-chromium alloy of predetermined iron-chromium ratio and intermediate carbon content.

8. Process for the recovery of iron and chromium in alloyed form from a complex material comprising iron oxide and chromium oxide that comprises fluxing said material to form a composite reduction charge, subjecting a first portion of said composite 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy of predetermined iron-chromium ratio and a waste slag product, subjecting a second portion of said composite charge to reduction smelting in the presence of a carbonaceous reducing agent in an amount controlled to effect the selective reduction to the metallic state of that portion of the iron in excess of 3-8% of the total iron content of said second charge portion with the production of low-carbon metallic iron and a chromium oxide-containing molten slag product, recycling said chromium oxide-containing molten slag product to the reduction smelting stage operating on said first charge portion, and blending said high-carbon iron-chromium alloy and said low carbon metallic iron to provide an iron-chromium alloy of predetermined iron-chromium ratio and intermediate carbon content.

9. Process for the production of alloyed steel from chrome-iron ores that comprises, subjecting a first ore fraction 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 and chromium oxide contained therein with the production of a crude high-carbon iron-chromium alloy and a waste slag product, subjecting a second ore fraction to reduction smelting in the presence of a carbonaceous reducing agent in an amount sufficient to effect the selective reduction to the metallic state of the major portion of the iron oxide content thereof with the production of a low-carbon metallic iron and a residual slag containing the chromium oxide content and the remainder of the iron content thereof, recycling said slag to a reduction smelting operation conducted on said first ore

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fraction, blending said high-carbon iron-chromium alloy with said low-carbon metallic iron to provide a master alloy of controlled intermediate carbon content, and refining said master alloy as necessary for the production and recovery of a chromium-alloyed steel product.

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