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(54) Title: PROCESSING OF METALLURGICAL SLAG

(57) Abstract: The invention relates to a method of processing metallurgical slag containing at least one desired metal slag compound. According to the method, the slag is admixed with a reductant and a preferred metal ore to obtain a reaction mixture. The reaction mixture is then heated to cause the reductant to reduce at least the desired metal slag compound, thereby to obtain a molten metal product. The molten metal product comprises at least the desired metal. The desired metal and the preferred metal may be the same, in particular manganese.

PROCESSING OF METALLURGICAL SLAG

THIS INVENTION relates to processing of metallurgical slag. More particularly, the invention relates to a method of processing metallurgical slag containing at least one desired metal slag compound and further relates to a metallurgical feedstock for processing. The invention extends to a molten metal product and a valuable by-product produced in accordance with the method of the invention.

In producing metal alloys by means of ore smelting, oxides of metal alloy components, for example manganese (IV) dioxide (MnO_2) and iron (III) oxide (Fe_2O_3), are reduced in the presence of a suitable reductant, such as carbon, to metals, thereby to produce a metal alloy product comprising the metals, such as ferromanganese (FeMn). Metallurgical slags containing non-reduced metal oxides and other impurities are produced in addition to the alloy product. In many cases, such non-reduced metal oxides contained in the slags include desired metal oxides, useful for alloying. In the production of high carbon ferromanganese (HCFeMn), for example, a slag is produced which typically has a relatively high manganese (Mn) content, usually in the form of manganese (II) oxide (MnO). As MnO is a thermodynamically stable oxide and reduction of the manganese ion to Mn with a carbon reductant usually occurs only at temperatures above 1420 °C, the further processing of such slags to reduce the desired metal compounds and obtain a metal alloy product is not generally considered to be economically viable. Producing a metal alloy product from such slags is further hampered by the presence of impurities, in particular large amounts of silica (SiO_2), contained in the slag. Silica presents a problem as, during reduction of a desired metal oxide in the slag, large amounts of silicon (Si) are formed due to simultaneous reduction of the silicon ion in the silica. This leads to an alloy product produced from the slag containing unacceptably high levels of Si. The reduction of silica to silicon can be counteracted by the addition of a calcium-containing fluxing agent, but this solution is not economically attractive, since large quantities of fluxing agent are required and addition of such large quantities of fluxing agent reduces the overall throughput of the system, thus also reducing metal alloy yield.

It is thus an object of the present invention to address the abovementioned difficulties in processing metallurgical slag by providing a means whereby metallurgical slags can be further processed to obtain a metal alloy product therefrom, which product conforms to desired specifications, *inter alia* of composition.

According to one aspect of the invention, there is provided a method of processing metallurgical slag containing at least one desired metal slag compound, the method including the steps of

admixing the slag with a reductant and a preferred metal ore to obtain a reaction mixture;

heating the reaction mixture to cause the reductant to reduce at least the desired metal slag compound, thereby to obtain a molten metal product, comprising at least the desired metal, and molten processed slag; and

separating the molten metal product from the processed slag.

In this specification, the phrase “desired metal slag compound” is to be understood to refer to a compound contained in the metallurgical slag which contains a metal which is desired to be included in the molten metal product. Further, “preferred metal ore” is to be understood to refer to an ore of a metal which metal is preferred also to be included in the molten metal product. It will therefore be appreciated that the adjectives “desired” and “preferred” are employed in qualifying the respective metals and the desirability of including these metals in the molten metal product.

The desired metal and the preferred metal may be the same metal. In a particular embodiment of the invention, the desired metal and the preferred metal may be manganese.

The desired metal slag compound may comprise a desired metal oxide. When the desired metal is manganese, the desired metal slag compound may be manganese (II) oxide (MnO).

The preferred metal may be expressed in the preferred metal ore in the form of a preferred metal compound. Typically, the preferred metal compound may comprise a preferred metal oxide. When the preferred metal is manganese, the ore may be a Mn-containing ore and the preferred metal oxide may be manganese (II) oxide. . It will be appreciated that, in the heating step, at least some of the preferred metal compound will also be reduced by the reductant, thereby contributing molten metal to the molten metal product.

The ore may comprise 10%-50%, by mass, of the reaction mixture. Typically, the ore comprises 15%-40%, by mass, of the reaction mixture.

Some of at least one of the desired metal and the preferred metal may be present in the reaction mixture in a native metallic form, the metals simply being melted in the heating step and being included in the molten metal product.

The method may include admixing a metal alloying component comprising at least one additional metal, other than the desired metal and the preferred metal, with the reaction mixture. The additional metal may be at least partly contained in at least one of the metallurgical slag and the preferred metal ore. The additional metal may be at least partly in native metallic form. Alternatively, or additionally, the additional metal may be at least partly expressed as an additional metal compound. Typically, the additional metal compound is in the form of an additional metal oxide. In a particular embodiment of the invention, the additional metal is iron and the additional metal compound comprises iron (III) oxide (Fe_2O_3). When the additional metal is at least partly in native metallic form, metal fines, such as Fe fines when the additional metal is iron and the alloy is a ferro-manganese alloy, may thus be employed in addition to or instead of additional metal-containing slags, e.g. iron-containing BOF slags.

It will be appreciated that the additional metal compound, when present, may also be reduced by the reductant in the heating step and may therefore contribute the additional metal to the molten metal product. In such a case, the molten metal product will thus be in the form of an alloy, comprising a molten mixture of at least the desired metal and the additional metal. When the desired metal is Mn and the metal alloying component is Fe, the alloy will thus be a ferro-manganese (FeMn) alloy, such as high carbon ferro-manganese (HCFeMn), medium carbon ferro-manganese (MCFeMn) or low carbon ferro-manganese (LCFeMn).

Metals other than the desired metal and the additional metal may be present in at least one of the ore and the slag. At least some of the other metals may be expressed as metal compounds capable of being reduced by the reductant. Typically, such other metal compounds comprise metal oxides, metal silicates, and mixtures thereof. Typically, such other compounds include silica (SiO_2), which may typically be present in the slag. At least some of the silica will therefore be reduced by the reductant in the heating step to form silicon (Si), which is incorporated in the molten metal product.

Naturally, other metals referred to above can also be present in the slag in a native, metallic form. Thus, these metals will also be melted in the heating step and be included in the molten metal product.

The reductant, the metal ore, and at least a part of the slag may be in solid form when being admixed to form the reaction mixture.

Alternatively, at least a part of the slag may be in molten form when being admixed, typically being at a temperature of 1100℃-1650℃, e.g. 1200℃-1550℃. This may be the case when raw slag is available in solid form, such as from a tip or dump located near a metallurgical furnace which produces raw slag in molten form with the slag thus readily being available in both solid and molten form. It will be appreciated that, through using molten slag, an energy reduction in the heating step may be achieved. It is expected that this reduction may be up to 35% or more of the heat energy which would be required in the absence of molten slag.

The method may include, prior to the admixing step, comminuting at least one of the slag, the reductant and the metal ore in solid form to obtain comminuted material. The comminuted material may be subjected, prior to the admixing step, to size classification to obtain a size fraction thereof having an average particle size of at most about 50mm. It will be appreciated that the obtained size fraction will then be admixed with the reductant to obtain the reaction mixture. The comminution of the raw slag, prior to admixing thereof with the reductant may, for example, be by crushing, to cause the size reduction thereof.

The reaction mixture may be heated in the heating step to a temperature from about 1350°C to about 1650°C. Typically, heating the reaction mixture is selected from being conducted on a continuous basis by means of an induction furnace or on a batch wise basis by means of an arc furnace. The arc furnace may be a submerged arc furnace or, more preferably, may be an open arc furnace. It is expected that an open arc furnace would be employed particularly when the reduction rate is to be retarded so as to ensure that the processed slag contains not more than 6% by mass MnO.

Notwithstanding the nature of the furnace used and the nature of the operation allowed by the furnace, i.e. continuous or batch wise, the other steps of the method may be conducted more-or-less continuous or batch wise, as desired.

The slag may be selected from metallurgical furnace slags obtained from one or more metallurgical furnaces used for metal, typically alloy production. The slag may typically be selected from manganese-containing slags, iron-containing slags, ferromanganese slags and mixtures thereof. Such slags may include not only basic oxygen furnace (BOF) slags or arc furnace (AF) slags obtained during steel production, but importantly also include slags obtained from furnaces used in the production of other metals, which may comprise alloys such as ferro-manganese alloys. Such slags may typically be toxic. The slags may be obtained from metal producers located off-site, or, optionally, after production may be used immediately on-site in molten form or, after solidification by air cooling thereof by natural convection on-site, may be stockpiled. Thus, a stockpile of raw slag may be provided from which raw slag to be processed in accordance with the method of the invention, may be withdrawn, continuously or batch wise, as desired, for further processing in accordance with the method of the invention.

Preferably therefore, the raw slag may comprise a mixture of at least one manganese-containing slag and at least one iron-containing slag, such as a BOF slag, so that the metal product comprises a ferro-manganese alloy. Preferably, however, the slag is a ferro-manganese slag, containing manganese and iron, typically in the forms of MnO and Fe_2O_3, originating from a ferro-manganese alloy production operation. The slag may, of course, also be a mixture of a ferro-manganese slag and one or more manganese-containing and/or iron-containing slag.

The manganese-containing slags may typically be obtained from ferro-manganese production, the manganese being in the form of MnO. Typically, the manganese-containing slag may comprise, by mass, 15%-30% manganese, expressed as MnO.

The iron-containing slag may be a slag obtained from a BOF steel production process. The iron-containing slag may typically comprise, by mass, 25%-50% iron, expressed as Fe_2O_3.

The reductant may be solid and may be any or more of a silicon-containing reductant, and an aluminium-containing reductant, a ferrosilicon-containing reductant, and a carbon-containing reductant. Preferably, the reductant is a carbon-containing reductant and is selected from coal and anthracite. Carbon-containing reductants, such as coal, are preferred by virtue of their ready availability at low cost and can be contrasted with aluminium-containing or ferrosilicon-containing reductants which, in certain circumstances, can be regarded as contaminants. The quality of carbon reductant employed will, of course, depend on the quality of pure carbon present in the reductant. For example, a typical coal reductant with an average carbon content of 50% by mass for manufacturing HCFeMn alloy will typically comprise about 10% by mass of total reaction mixture feed. It will, however, be appreciated that this quantity will vary from case to case.

Various optional additives or reagents, in addition to the reductant, may be added to the reaction mixture. Typically, the method includes admixing a calcium-containing fluxing agent with the reaction mixture, such as lime (CaO), typically in the form of limestone ($CaCO_3$). The addition of the calcium-containing fluxing agent may be used to optimize the basicity of the reaction mixture, expressed in a $CaO:SiO_2$ mass ratio, thereby to limit the formation of silicon and the inclusion thereof in the metal product.

The composition of the reaction mixture may be selected to produce a molten metal product, in the form of an alloy, having, by mass, a silicon content of between 0.4 % and 0.9%, typically 0.5 – 0.7 %. When the molten metal product is in the form of a ferromanganese alloy, the composition of the reaction mixture will typically be selected is such that the alloy has a manganese content of 70% to 90%, by mass, preferably 76% to 80%, and an iron content of 5% to 20% by mass, preferably 6% to 15%. Typically, the composition of the reaction mixture may further be selected such that its basicity, expressed as $CaO+MgO/SiO_2$ by mass, is in the region of 1.3 to 1.5 with the final basicity of the slag after reduction, measured as CaO/SiO2 by mass, being between 1 and 1.25.

Separating the molten metal product, or alloy, from the molten processed slag may be by way of gravity separation. The molten metal product typically has a higher density than the molten processed slag, and therefore the molten processed slag will typically float as a layer on the molten metal product. The separation may thus, for example, take place in the furnace itself, or in another vessel, such as a tilting crucible, which may have a tapping opening at a low level. The molten metal product can then be tapped from the vessel at the low level and the molten processed slag can be poured or decanted, e.g. as an overflow from the vessel at a high level, by tilting the vessel. Instead, the slag can be decanted first, followed by decanting of the metal product.

The separation of the processed slag and the metal product, both in molten form, from each other, has a major advantage in that the molten metal product can be obtained in relatively slag-free form, uncontaminated by the processed slag. The gravity separation made possible by this feature of the method of the invention furthermore lends itself to a variety of different separation methods, such as tapping, decanting, pouring, etc, and thus adds versatility to the method of the invention. Furthermore, the use of electrically powered furnaces, such as induction or arc furnaces, facilitates keeping the slag and the metal product at a temperature at which they are molten at all times, after the reduction has taken place and until they are separated. It is to be emphasised that, regardless of the reaction temperatures employed, the heating should act at all times to keep the metal product and the processed slag molten, at least until they have been separated from each other.

The method may further include subjecting the molten processed slag, when separated from the molten metal product, to downstream processing to obtain therefrom a valuable by-product. In one embodiment of the invention, the method may include allowing the molten processed slag to solidify to air-cooling, subjecting the solidified processed slag to comminution to achieve size reduction thereof and rendering the slag in the form of an aggregate, with the aggregate being the valuable by-product. Alternatively, the method may include causing the molten processed slag to solidify by contacting it with liquid water to cause granulation of the processed slag and obtain a granulated processed slag, with the granulated processed slag then being the valuable by-product. In such a case, the method may include dewatering the granulated processed slag. The granulated processed slag may further be comminuted, for example by crushing and/or milling, for example by milling during or after the dewatering thereof. The comminuted dewatered processed slag may then be stockpiled before use or before onward sale to users, or may be immediately on site for the manufacture of end product. Typically, the granulated processed slag is useful as an extender.

While the processed air-cooled slag product in aggregate form will usually be regarded as a final product for sale on to users thereof in the construction or building industry, the granulated processed slag product can be regarded as an intermediate product which can be stockpiled for further processing later, or can be sold on, for use as an extender or filler, to manufacturers of, for example, bricks, ready-mix concretes, slag-extended blended cements, or the like, after grinding or milling, if necessary, to a sufficiently small particle size. Instead, the granulated processed slag intermediate product may be processed further to produce a more or less final processed slag product.

The invention also extends to a molten metal product and to a valuable processed slag product, when produced in accordance with the method of the invention as described and defined above.

In accordance with another aspect of the invention, there is provided a metallurgical feedstock for processing, the feedstock comprising a mixture of

metallurgical slag containing a desired metal compound;
a reductant; and
a preferred metal ore.

The desired metal and the preferred metal may be as hereinbefore described. Thus, the desired metal and the preferred metal may be the same metal, typically manganese.

The desired metal slag compound may at least partly comprise a desired metal oxide. When the desired metal is manganese, the desired metal oxide may typically be manganese (II) oxide.

The preferred metal may be expressed at least partly in the preferred metal ore in the form of a preferred metal compound, typically a preferred metal oxide. Thus, when the desired metal is manganese, the desired metal oxide may typically be manganese (II) oxide.

The metallurgical slag may be as hereinbefore described and may be selected from manganese-containing slags, iron-containing slags, ferro-manganese containing slags and mixtures thereof.

The reductant may also be as hereinbefore described and may comprise a reductant for reducing the desired metal compound, preferably a carbon-containing reductant.

The preferred metal ore may be as hereinbefore described and may comprise 10% to 50%, more particularly 15% to 40%, by mass, of the feedstock.

The feedstock may include a metal alloying component containing an additional metal to the desired metal and the preferred metal. The metal alloying component and the additional metal may be as hereinbefore described. Preferably, the additional metal is iron.

Typically, the reductant, the ore and at least a part of the metallurgical slag may be in solid form. It is expected that the metallurgical slag may, however, be at least partly in molten form.

The invention will now be described, with reference to the following non-limiting illustrative examples.

EXAMPLES

In order to assess the viability of the method of the invention, a theoretical model of the method of the invention was prepared and executed for various scenarios of slag and ore inputs.

Approach

The model involved preparing mass and energy balances for the heating step of the invention, i.e. for the various reduction reactions taking place in the heating step, for various scenarios of input materials. This was done with a view to predict what the effect of the addition of different quantities of a manganese (Mn) ore, in the form of a ferromanganese (FeMn) ore, would be on the composition of the metal product produced in the reduction of to two different raw input slags.

The model was prepared for a ferro-manganese (FeMn) slag and a silicon-manganese (SiMn) slag.

As mentioned above, the aim of the model was to predict the effect which the addition of the Mn ore, respectively to the FeMn slag and to the SiMn slag, in accordance with the method of the invention, can have on the composition of the metal product obtained by reduction of the slags by a suitable reductant, particularly as regards silicon content of the metal product. The model also aimed to determine what effect such Mn ore addition would have on the amount of lime fluxing agent required to limit silicon content in the metal product.

The Mn ore was taken to have an essential chemical analysis, on a mass basis, as follows:

Mn	37.9%
Fe	5.4%
MgO	2.0%
Al_2O_3	0.3%
SiO_2	6.3%
CaO	13.8%
P_2O_5	0.018%

It was assumed that all the Mn was present in the ore as MnO and that all the Fe was present in the ore as Fe_2O_3. It should be kept in mind, however, that this assumption could be improved by mineralogical analysis of the ore. However, it is expected that an error in this assumption would not have an affect on a mass balance in respect of manganese, but rather on the amount of reductant required.

Further input data and process parameters used in the model were as shown in Table 1 below:

TABLE 1: Process parameters

Parameter	Description	Value
Batch mass	The mass of a single batch that is processed in the furnace.	15,000 kg
Reaction temperature	The temperature at which carbo-thermic reactions occur in the slag bath and at which the chemical equilibrium is calculated.	1,500 °C
Carbon bypassed	The mass fraction of carbon bypassing the process (after dust loss) and do not participate in reduction reactions.	30 %
Offgas Temperature	The temperature of the gas exiting the furnace.	1650 °C
Slag Temperature	The temperature at which the slag is tapped from the furnace.	1650 °C
Alloy Temperature	The temperature at which the alloy is tapped from the furnace.	1600 °C
Offgas Temperature (after final heat loss)	The temperature of the offgas after the final point of heat loss.	160 °C
Furnace rating	The smelting furnace power rating.	20 MVA
Power factor	The smelting furnace power factor.	0.7085
Load factor	The smelting furnace load factor.	90%
Operating time	The smelting furnace operating time.	95%
Availability	The smelting furnace availability.	90%
Furnace Excess Power	The extra power that has to be added to the furnace to smelt raw material. This includes the furnace heat losses.	3 MW

Parameter	Description	Value
Alloy Recovery	The percentage of the alloy produced in the furnace that is recovered.	98%
Slag Recovery	The percentage of the slag produced in the furnace that is recovered.	98%
Alloy Carbon Content	The mass fraction of Carbon in the alloy produced.	7.5%

In Table 2 below, the composition and nature of each of the input streams, used in the mass and energy balance model, save for the composition of the Mn ore which is given above, are summarised. For each stream, the mass per batch, temperature, and mass fraction bypassing the process to dust must be specified in order to execute the model. The chemical species for each stream are listed for which the mass percentages need to be provided, as well as the calculations that are made to transfer the chemical analyses before they are used in the mass and energy balance. The values of the chemical analysis used for scenarios that were executed with the model are also provided.

For Table 2 below, it should be noted that the all the streams are assumed to enter the process at ambient temperature (25℃) while the molten slag streams enter at 1250℃. This assumption is based thereon that the molten slag will be tapped from the furnace at 1400℃ and is expected to loose heat at a rate of 50℃/h, which implies 3h from being tapped until feed into the furnace.

It should further be noted that, although three BOF slags, designated respectively as BOF(I), BOF(II) and BOF(III), are identified, only BOF(II) slag was used in executing the model.

TABLE 2: Input streams

Stream	Chemical Species	Temperature	Dust	Calculations
FeMn Molten Slag	26.33% MnO 31.4% CaO 5.52% MgO 32.24% SiO_2 0.5% FeO 4.83% Al_2O_3	1250℃	0%	Use percentages as is but for the representative chemical species.
FeMn Air Cooled Slag	Same as above.	25℃	5%	Use percentages as is but for the representative chemical species.
SiMn Molten Slag	17.36% MnO 26.34% CaO 4.86% MgO 48.47% SiO_2 0.64% FeO 3.19% Al_2O_3	1250℃	0%	Use percentages as is but for the representative chemical species.

Stream	Chemical Species	Temperature	Dust	Calculations
SiMn Air Cooled Slag	Same as above.	25°C	5%	Use percentages as is but for the representative chemical species.
BOF(I) Slag	10.34% MgO 21.3% SiO_2 1.86% Al_2O_3 0.63% P 1.17% S 38.28% CaO 4.78% MnO 23.06% FeO	25°C	5%	Use percentages as is but for the representative chemical species.
BOF(II) Slag	4.48% MgO 16.96% SiO_2 4.18% Al_2O_3 0.24% P_2O_5 29.91% CaO 1.06% MnO 40.01% Fe_2O_3	25°C	5%	Use percentages as is but for the representative chemical species.
BOF(III) Slag	7.4% MgO 9.57% SiO_2 5.7% Al_2O_3 31.1% CaO 3.24% MnO 38.7% FeO	25°C	5%	Use percentages as is but for the representative chemical species.
Coal	Proximate (Dry basis): 3.94% H_2O 50.7% Fixed C 30.6% Volatiles 16.7% Ash 1% S 0.6% P_2O_5 Ash: 57.8% SiO_2 24.2% CaO 0.3% MgO 30.7% Al_2O_3 6.7% Fe_2O_3	25°C	5%	Normalise proximate analysis to 100% minus % H_2O, and then the ash analysis to add up to the ash percentage. Use the calculated specie percentages for the representative chemical species. Use the ultimate analysis specie percentages for the representative species (except C).
Anthracite	Proximate (Dry basis): 2.83% H_2O 78.13% Fixed C 4.7% Volatiles 14.34% Ash 1.5% S 0.048% P_2O_5 Ash: 56.33% SiO_2 3.38% CaO 1.02% MgO 25.66% Al_2O_3 6.24% Fe_2O_3 Ultimate: 90.46% C 3.77% H 2.39% N 1.8% S 1.58% O	25°C	5%	Normalise proximate analysis to 100% minus % H_2O, and then the ash analysis to add up to the ash percentage. Use the calculated specie percentages for the representative chemical species. Use the ultimate analysis specie percentages for the representative species (except C).
FeSi	100% FeSi	25°C	5%	Use percentages as is but for the representative chemical species.
SiC	4.53% C 88% SiC 1.5% Al_2O_3 0.29% FeO 0.22% CaO 0.11% MgO	25°C	5%	Use percentages as is but for the representative chemical species.
Burnt Lime	1.3% SiO2 0.2% Fe2O3 87% CaO 1.6% MgO 0.2% Al_2O_3 1% Mn_2O_3	25°C	5%	Use percentages as is but for the representative chemical species.

Stream	Chemical Species	Temperature	Dust	Calculations
	3.6% $CaCO_3$			
Combustion/ Dilution Air	21 vol% O_2 79 vol% N_2	25°C	-	Use percentages as is but for the representative chemical species.

In the case of carbonaceous materials, i.e. coal and anthracite, where an ultimate analysis was not available, assumptions had to be made regarding the volatile matter content of the materials.

The process model parameters calculated as desired outputs from the mass and energy balance are summarised in Table 3, where applicable target values are given for which the input parameter values must be adjusted.

TABLE 3: Desired outputs

Parameter	Description	Units	Specification
Slag Percentage Solids	The mass fraction of slag solids predicted in the slag output stream. This parameter is important to monitor to ensure that the slag can be tapped from the furnace.	5% - 9%	AVE. 5%
Basicity (CaO + MgO / SiO_2)	The slag basicity calculated as the mass fraction of CaO and MgO in the slag divided by the fraction of SiO_2.		1.35 – 1.4
Basicity (CaO / SiO_2)	The slag basicity calculated as the mass fraction of CaO in the slag divided by the fraction of SiO_2.		1.1 – 1.2

It is expected that the desired values for slag percentage solids will be determined more accurately by pilot scale testing of the method of the invention.

Scenarios

The following scenarios, as set out below, were considered by the mass and energy balance model for the heating step of the method of the invention, respectively for the FeMn slag, in combination with BOF(II) slag, and for the SiMn slag:

1. FeMn slag

   Each scenario was executed with a reaction mixture comprising variable quantities of BOF slag and/or Fe fine, and variable amounts of Mn ore per 100kg of Mn ore plus FeMn slag air cooled slag as set out hereunder:

   a. Mn ore (kg/100 kg slag feed) = 0% + air cooled FeMn slag + BOF (II)

   b. Mn ore (kg/100 kg slag feed) = 15% + air cooled FeMn slag + BOF (II)

c. Mn ore (kg/100 kg slag feed) = 0% + air cooled FeMn slag + Fe fines
d. Mn ore (kg/100 kg slag feed) = 15% + air cooled FeMn slag + Fe fines
e. Mn ore (kg/100 kg slag feed) = 20% + air cooled FeMn slag + Fe fines
f. Mn ore (kg/100 kg slag feed) = 25% + air cooled FeMn slag + Fe fines

2. SiMn slag

Each scenario was executed with a reaction mixture comprising 0% BOF slag/Fe fines, air cooled SiMn slag and variable amounts of Mn ore per 100kg of molten SiMn slag, as set out hereunder:

a. Mn ore (kg/100 kg slag feed) = 0% + air cooled SiMn slag
b. Mn ore (kg/100 kg slag feed) = 37.5% + air cooled SiMn slag

Mass and energy balances were prepared for the various chemical species taking part in reduction reactions which would, thermodynamically and theoretically, take place in each of the abovementioned scenarios. The mass and energy balances were then solved for a reaction temperature of 1500℃. In each case, the mass and energy balances were solved for amounts of reductant and lime required to meet a desired final slag basicity, expressed as a ratio of CaO concentration/SiO_2 by mass. In the case of the FeMn slag, the desired basicity was 1.2 and in the case of the SiMn slag, the desired basicity was 1.1.

The results of the mass and energy balances executed in respect of the FeMn slag and the SiMn slag are presented respectively in Table 4 below.

TABLE 4: Comparative results for FeMn and SiMn slag

		FeMn slag BOF (II)	**FeMn slag + Mn ore BOF (II)**	**FeMn slag Fe Fines**	**FeMn slag + Mn ore Fe Fines**	**FeMn slag + Mn ore Fe Fines**	**FeMn slag + Mn ore Fe Fines**	**FeMn slag No Fe/BOF(II)**	**FeMn slag + Mn ore No Fe/BOF(II)**	**FeMn slag + Mn ore No Fe/BOF(II)**	**FeMn slag + Mn ore No Fe/BOF(II)**	**SiMn slag No Fe/BOF(II)**	**SiMn slag + Mn ore No Fe/BOF(II)**
INPUT		0	15	0	15	20	25	0	15	20	25	0	60
Slag Cold	[kg/batch]	11747.5	9953.8	12133.8	10378.9	9778.1	9187.5	12500.0	10757.8	10159.2	9548.0	10550.0	6925.0
Slag Hot	[kg/batch]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOF(II) Slag/Fe Fines	[kg/batch]	952.5	976.4	466.2	439.3	438.2	437.5	0.0	0.0	0.0	0.0	0.0	0.0
Mn ore	[kg/batch]	0.0	1749.8	0.0	1731.9	2303.7	2875.0	0.0	1722.2	2290.8	2852.0	0.0	4155.0
Coal	[kg/batch]	1550.0	1820.0	1450.0	1700.0	1800.0	1900.0	1450.0	1720.0	1800.0	1900.0	800.0	1720.0
Lime	[kg/batch]	750.0	500.0	950.0	750.0	680.0	600.0	1050.0	800.0	750.0	700.0	3650.0	2200.0
Combustion Air	[kg/batch]	27000	27000	27000	27000	27000	27000	27000	27000	27000	27000	27000	27000
Combustion Air	[Nm3/batch]	20979	20979	20979	20979	20979	20979	20979	20979	20979	20979	20979	20979
Dilution Air	[kg/batch]	97000	97000	97000	97000	97000	97000	97000	97000	97000	97000	97000	97000
Dilution Air	[Nm3/batch]	75369	75369	75369	75369	75369	75369	75369	75369	75369	75369	75369	75369
Batch Mass	[kg/batch]	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Coal	[kg/t slag feed]	**122.0**	**143.5**	**115.1**	**135.5**	**143.8**	**152.0**	**116.0**	**137.8**	**144.6**	**153.2**	**75.8**	**155.2**
Lime	[kg/t slag feed]	**59.1**	**39.4**	**75.4**	**59.8**	**54.3**	**48.0**	**84.0**	**64.1**	**60.2**	**56.5**	**346.0**	**198.6**
BOF(II) Slag/Fe Fines	[kg/t slag feed]	**75.0**	**77.0**	**37.0**	**35.0**	**35.0**	**35.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Mn ore (as solid slag)	[kg/t slag feed]	**0.0**	**138.0**	**0.0**	**138.0**	**184.0**	**230.0**	**0.0**	**138.0**	**184.0**	**230.0**	**0.0**	**375.0**
Slag Cold	[kg/100 kg slag feed]	92.5%	78.5%	96.3%	82.7%	78.1%	73.5%	100.0%	86.2%	81.6%	77.0%	100.0%	62.5%
Slag Hot	[kg/100 kg slag feed]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BOF(II) Slag/Fe Fines	[kg/100 kg slag feed]	7.5%	7.7%	3.7%	3.5%	3.5%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mn ore	**[kg/100 kg slag feed]**	**0.0%**	**13.8%**	**0.0%**	**13.8%**	**18.4%**	**23.0%**	**0.0%**	**13.8%**	**18.4%**	**23.0%**	**0.0%**	**37.5%**
Mn ore	[kg/100 kg molten slag]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mn ore	[kg/100 kg molten slag + Mn ore]	0.0%	15.0%	0.0%	14.3%	19.1%	23.8%	0.0%	13.8%	18.4%	23.0%	0.0%	37.5%
Operating Temperature	[°C]	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Slag Temperature	[°C]	1650	1650	1650	1650	1650	1650	1650	1650	1650	1650	1650	1650
AlloyTemperature	[°C]	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Effective Power Input	[MW]	15.67	15.67	15.67	15.67	15.67	15.67	**15.67**	**15.67**	**15.67**	**15.67**	**15.67**	**15.67**
Heat Losses	[MW]	3.00	3.00	3.00	3.00	3.00	3.00	**3.00**	**3.00**	**3.00**	**3.00**	**3.00**	**3.00**
OUTPUT													
Slag	[kg/batch]	10222	9121	10258	9234	8848	8460	10547	9474	9135	8749	12237	9007
Alloy	[kg/batch]	**2265**	**2698**	**2355**	**2747**	**2903**	**3059**	**2088**	**2507**	**2636**	**2791**	**946**	**2371**
Dust	[kg/batch]	1044	1076	1024	1053	1066	1079	1026	1059	1068	1081	896	1029
Uncombusted Furnace Offgas	[kg/batch]	1483	1744	1358	1602	1700	1798	1379	1645	1725	1824	812	1670
Uncombusted Furnace Offgas	[Nm3/batch]	2097	2463	1938	2278	2414	2550	1956	2325	2435	2571	1124	2348
Combusted Furnace Offgas	[kg/batch]	28760	29067	28613	28898	29013	29128	28633	28943	29036	29151	27968	28985
Combusted Furnace Offgas	[Nm3/batch]	22065	22260	21982	22163	22236	22309	21982	22179	22238	22311	21552	22197
Diluted Offgas (800°C)	[kg/batch]	126526	126820	126382	126655	126766	126877	126406	126704	126793	126905	125708	126699
Diluted Offgas (800°C)	[Nm3/batch]	97377	97572	97294	97475	97548	97621	97294	97491	97550	97623	96864	97509
Combusted Offgas Temperature	[°C]	1057	1246	978	1159	1228	1296	987	1181	1237	1304	498	1198
Basicity (CaO + MgO / SiO2)		**1.38**	**1.38**	**1.37**	**1.37**	**1.38**	**1.38**	**1.36**	**1.36**	**1.37**	**1.38**	**1.31**	**1.32**
Basicity (CaO / SiO2)		**1.20**	**1.19**	**1.19**	**1.20**	**1.20**	**1.20**	**1.19**	**1.19**	**1.19**	**1.20**	**1.20**	**1.20**
Slag % Solids		7.4%	6.2%	7.9%	8.1%	8.3%	8.0%	7.2%	6.5%	7.6%	8.7%	9.1%	9.0%
% Slag Product Recovery (to slag feed)		80%	72%	81%	74%	71%	68%	84%	76%	73%	71%	116%	81%
% Alloy Recovery (to slag feed)		**17.8%**	**21.3%**	**18.7%**	**21.9%**	**23.2%**	**24.5%**	**16.7%**	**20.1%**	**21.2%**	**22.5%**	**9.0%**	**21.4%**
% Mn Recovery		74.5%	78.5%	74.9%	78.3%	80.0%	81.5%	75.1%	78.4%	79.1%	80.8%	53.9%	77.7%
Slag/Alloy		4.51	3.38	4.36	3.36	3.05	2.77	5.05	3.78	3.47	3.14	12.94	3.80
Chemical Energy Requirement	[MWh/batch]	13.3	13.6	13.1	13.4	13.5	13.6	13.2	13.5	13.6	13.7	11.7	12.9
Chemical Energy Requirement	**[kWh/t slag feed]**	**1047.1**	**1075.8**	**1040.3**	**1064.0**	**1076.6**	**1089.8**	**1053.0**	**1082.1**	**1088.6**	**1101.0**	**1104.4**	**1163.7**
Offgas Temperature (after dilution air)	[°C]	342.16	393.23	320.01	367.89	386.81	405.59	323.47	375.17	390.28	409.10	198.40	377.07
Heat loss required from offgas (800-160°C)	[MWh/batch]	6.7	8.7	5.9	7.7	8.4	9.2	6.0	8.0	8.6	9.3	1.4	8.1
OUTPUT ANALYSES													
Slag Analysis (mass %):													
Al2O3		6.4%	6.4%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	2.9%	3.3%
SiO2		36.5%	36.5%	36.9%	36.7%	36.7%	36.8%	37.1%	37.0%	36.9%	36.8%	39.3%	38.9%
CaO		43.7%	43.5%	44.0%	43.9%	44.0%	44.1%	44.2%	43.9%	44.0%	44.2%	47.0%	46.5%
FeO		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MgO		6.8%	6.9%	6.5%	6.5%	6.6%	6.6%	6.4%	6.4%	6.4%	6.5%	4.4%	4.8%
PbO		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZnO		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MnO		**6.5%**	**6.6%**	**6.5%**	**6.8%**	**6.6%**	**6.4%**	**6.3%**	**6.6%**	**6.7%**	**6.4%**	**6.4%**	**6.5%**
Cr2O3		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alloy Analysis (mass %):													
Al		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
C		**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**	**7.5%**
Cr		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fe		**14.3%**	**15.4%**	**14.4%**	**14.7%**	**14.9%**	**15.0%**	**2.7%**	**5.5%**	**6.3%**	**6.9%**	**6.3%**	**10.9%**
Mn		**76.5%**	**76.0%**	**76.3%**	**76.6%**	**76.6%**	**76.6%**	**89.0%**	**86.3%**	**85.6%**	**85.0%**	**78.6%**	**79.7%**
Mo		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ni		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pb		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
S		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Si		**1.5%**	**0.91%**	**1.6%**	**0.93%**	**0.8%**	**0.7%**	**0.7%**	**0.5%**	**0.4%**	**0.4%**	**7.6%**	**1.7%**
Zn		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
P		0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.0%	0.2%
Uncombusted Furnace Offgas Analysis (vol%):													
H2		48.4%	48.4%	49.0%	48.9%	48.8%	48.8%	48.6%	48.5%	48.4%	48.4%	46.6%	47.9%
N2		1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.5%	1.6%
O2		3.0%	3.3%	3.4%	3.6%	3.7%	3.8%	2.2%	2.7%	2.9%	3.0%	1.8%	2.6%
H2O		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
CO		45.9%	45.5%	44.9%	44.7%	44.7%	44.6%	46.4%	46.0%	45.8%	45.7%	49.2%	46.8%
CO2		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SO2		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SO3		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CALCULATIONS													
Consumption	[batches/day]	22.87	22.29	23.20	22.77	22.56	22.32	23.10	22.52	22.44	22.27	26.10	23.58
Consumption	[t slag feed/day]	290.41	282.66	292.29	285.80	282.44	279.02	288.77	281.01	279.33	276.17	275.35	261.31
Consumption	[t slag feed/annum]	105998.3	103171.4	106685.1	104317.9	103089.9	101841.5	105399.5	102567.3	101956.8	100803.1	100501.8	95377.1
Production Rate	[h/batch]	1.05	1.08	1.03	1.05	1.06	1.08	1.04	1.07	1.07	1.08	0.92	1.02

Discussion

From the results set out in Table 4 above, the following observations were made:

Reduced alloy silicon content:

The silicon content in the metal alloy product decreases when Mn ore is added to the feed slag. An alloy is predicted with a composition closer to the desired specification in the case of the SiMn slag, and within the desired specification in the case of the FeMn slag.

It is important to note that, in the model used, the reduction reactions are modelled by calculating thermodynamic equilibrium at each reduction step and therefore ideal conditions were assumed where mass transfer does not limit the reduction reactions. This then means that the predicted silicon content in the alloy is expected to be the maximum value possible. In practice, it is expected the silicon content will be lower than predicted, due to mass transfer limitations reducing the reduction rate of the SiO_2 to Si.

Alloy yield:

The alloy yield (in kg per 100 kg slag and FeMn ore feed) increases with the addition of Mn ore to the slag feed. In the case of the SiMn slag feed, this increase is significant.

Lime requirement:

The requirement for lime in the feed mixture is significantly reduced when Mn ore is added to the feed mixture. Less CaO is therefore required to obtain the desired CaO/SiO2 ratio in the product slag, comprising the processed slag and the molten metal.

Reductant requirement:

The manganese oxide and iron oxide content of the FeMn ore increases the total amount of oxides which may be reduced, thus requiring more reductant to reduce the oxides to alloy species when the ore is added to FeMn slag or SiMn slags.

Liquidus temperature and slag solids for FeMn slag:

An increase in the final slag liquidus temperature is predicted when Mn ore is added to the FeMn slag, as well as more solids (5-7%) in the final slag. This is a result of the CaO/SiO_2 being set to 1.2 . To obtain the higher ratio, more lime had to be added which resulted in the solid solution phase Ca_2SiO_4 becoming more stable around the operating temperature. A higher liquidus temperature is therefore necessary to melt all the solids in the liquid slag.

Metal product manganese content:
In the case of the SiMn slag feed, an increase in manganese content of the metal product is predicted when the Mn ore is added to the feed.

Alloy silicon content for higher basicities:
The FeMn slag scenarios were also solved for a final slag CaO/SiO_2 ratio of 1.1 rather than the 1.2 value on which the results are based. At the lower basicities, a higher silicon content in the alloy is predicted, but still lower than that where no Mn ore was added.

At the higher CaO/SiO_2 ratios the Ca_2SiO_4 solid solution phase becomes more stable which appears to inhibit the reduction of SiO_2 from the slag and lowers the Silicon content in the alloy predicted. It therefore appears to be more feasible to operate the process at the higher CaO/SiO_2 ratio.

Use of Fe fines as alternative to BOF slags
From the results presented in Table 4 the above conclusions can be drawn for the effect of the addition of Mn ore to the FeMn and SiMn slags on alloy recovery. However, the results of the execution of the model for Fe fines used as alternative to BOF slags predict that Fe fines is a viable alternative to BOF slags.

Conclusion

The Applicant has thus unexpectedly found that the reduction of a metallurgical slag, containing a desired metal compound, in the presence of a metal ore limits the reduction of silica contained in the slag and therefore limits the amount of silicon contained in a metal alloy product, which is produced in accordance with the method of the invention. It has thus unexpectedly been found that the method of the invention enables the production of a commercially exploitable alloy from metallurgical slags which contain unreduced desired metal compounds.

The Applicant has also found that the quantity of calcium-containing fluxing agent, such as lime (CaO), typically in the form of limestone ($CaCO_3$), required to achieve or to maintain a desired basicity of the reaction mixture, expressed as $CaO:SiO_2$ decreases due to the presence of the ore in the reaction mixture, leading to higher throughput and higher metal product yield.

The Applicant has also found that an additional advantage of the invention is that the processed slag obtained in accordance with the method of the invention is amenable to downstream processing to produce cement extender products which comply with toxicological and technical specifications.

The Applicant has further found that, when Fe-containing slags are used or required, these Fe-containing slags may effectively be substituted with another source of Fe, particularly Fe-fines.

CLAIMS:

1. A method of processing metallurgical slag containing at least one desired metal slag compound, the method including the steps of

admixing the slag with a reductant and a preferred metal ore to obtain a reaction mixture;

heating the reaction mixture to cause the reductant to reduce at least the desired metal slag compound, thereby to obtain a molten metal product, comprising at least the desired metal, and molten processed slag; and

separating the molten metal product from the processed slag.

2. The method according to Claim 1, wherein the desired metal and the preferred metal are the same metal.

3. The method according to Claim 2, wherein the desired metal and the preferred metal are manganese.

4. The method according to any of Claims 1 to 3, wherein the desired metal slag compound at least partly comprises a desired metal oxide.

5. The method according to Claim 4, wherein the desired metal oxide is manganese (II) oxide.

6. The method according to any of claims 1 to 5 inclusive, wherein the preferred metal is expressed at least partly in the preferred metal ore in the form of a preferred metal compound.

7. The method according to Claim 6, wherein the preferred metal compound comprises a preferred metal oxide.

8. The method according to Claim 7, wherein the preferred metal oxide is manganese (II) oxide.

9. The method according to any of the preceding claims, wherein the ore comprises 10% to 50%, by mass, of the reaction mixture.

10. The method according to any of the preceding claims, wherein at least some of at least one of the desired metal and the preferred metal is present in the reaction mixture in native metallic form.

11. The method according to any of the preceding claims, which includes admixing a metal alloying component comprising at least one additional metal other than the desired metal and the preferred metal with the reaction mixture.

12. The method according to Claim 11, wherein the additional metal is at least partly contained in at least one of the metallurgical slag and the preferred metal ore.

13. The method according to Claim 11 or Claim 12, wherein the additional metal is present at least partly in native metallic form.

14. The method according to any of claims 11 to 13 inclusive, wherein the additional metal is at least partly expressed as an additional metal compound.

15. The method according to Claim 14, wherein the additional metal compound comprises an additional metal oxide.

16. The method according to Claim 15, wherein the additional metal is iron and the additional metal oxide is iron (III) oxide.

17. The method according to any of claims 11 to 16 inclusive, wherein the molten metal product is in the form of a metal alloy comprising a molten mixture of at least the desired metal and the additional metal.

18. The method according to Claim 17, wherein the desired metal is manganese, the additional metal is iron, and the metal alloy is ferro-manganese.

19. The method according to any of the preceding claims, wherein the reductant, the metal ore, and at least a part of the slag are in solid form when being admixed.

20. The method according to any of the preceding claims, wherein at least a part of the slag is in molten form, with the reductant and the metal ore being in solid form.

21. The method according to any of the preceding claims which includes, prior to the admixing step, comminuting at least one of the slag, the reductant and the metal ore in solid form to obtain comminuted material.

22. The method according to Claim 21, which includes, prior to the admixing step, subjecting the comminuted material to size classification to obtain a size fraction thereof having an average particle size of at most about 50mm.

23. The method according to any of the preceding claims, wherein the reaction mixture is heated to a temperature from about 1350℃ to about 1650℃.

24. The method according to any of the preceding claims, wherein heating the reaction mixture is selected from being conducted on a continuous basis by means of an induction furnace or on a batch wise basis by means of an arc furnace.

25. The method according to any of the preceding claims, wherein the slag is selected from metallurgical furnace slags obtained from one or more metallurgical furnaces used in metal production.

26. The method according to any of the preceding claims, wherein the slag is selected from manganese-containing slags, iron-containing slags, ferromanganese slags, and mixtures thereof.

27. The method according to Claim 26, wherein the manganese-containing slags comprise 15% to 30%, by mass, manganese expressed as manganese (II) oxide.

28. The method according to Claim 26, wherein the iron-containing slags comprise 25% to 50%, by mass, iron expressed as iron (III) oxide.

29. The method according to any of the preceding claims, wherein the reductant is any one or more of a silicon-containing reductant, an aluminum-containing reductant, a ferrosilicon-containing reductant and a carbon-containing reductant.

30. The method according to Claim 29, wherein the reductant is a carbon-containing reductant and is selected from coal and anthracite.

31. The method according to any of the preceding claims, which includes admixing a calcium-containing fluxing agent with the reaction mixture.

32. The method according to any of the preceding claims, wherein the molten metal product is in the form of an alloy having a silicon content of between 0.4 % and 0.9% by mass.

33. The method according to any of the preceding claims, wherein the molten metal product comprises a ferromanganese alloy and has a manganese content of 70% to 90% by mass and an iron content of 5% to 20% by mass.

34. The method according to any of the preceding claims, wherein the reaction mixture has a basicity, expressed as $CaO+MgO/SiO_2$ by mass, from 1.3 to 1.5 and the processed slag has a final basicity, expressed as CaO/SiO2 by mass, from 1 to 1.25.

35. The method according to any of the preceding claims, wherein separating the molten metal product from the processed slag is by way of gravity separation.

36. The method according to any of the preceding claims, which includes subjecting the molten processed slag, when separated from the molten metal product, to downstream processing to obtain therefrom a valuable by-product.

37. The method according to Claim 36, which includes allowing the molten processed slag to solidify through air-cooling, subjecting the solidified processed slag to comminution to achieve size reduction thereof and rendering the slag into aggregate, with the aggregate being the valuable by-product.

38. The method according to Claim 36, which includes causing the molten processed slag to solidify by contacting it with liquid water to cause granulation of the processed slag and obtain a granulated processed slag, with the granulated processed slag being the valuable by-product.

39. A metallurgical feedstock for processing, the feedstock comprising a mixture of

metallurgical slag containing a desired metal compound;
a reductant; and
a preferred metal ore.

40. The feedstock according to Claim 39, wherein the desired metal and the preferred metal are the same metal.

41. The feedstock according to Claim 40, wherein the desired metal and the preferred metal are manganese.

42. The feedstock according to any of claims 39 to 41, wherein the desired metal slag compound at least partly comprises a desired metal oxide.

43. The method according to Claim 42, wherein the desired metal oxide is manganese (II) oxide.

44. The method according to any of claims 39 to 43 inclusive, wherein the preferred metal is expressed at least partly in the preferred metal ore in the form of a preferred metal compound.

45. The method according to Claim 44, wherein the preferred metal compound comprises a preferred metal oxide.

46. The method according to Claim 45, wherein the preferred metal oxide is manganese (II) oxide.

47. The feedstock according to Claim 39, wherein the metallurgical slag is selected from manganese-containing slags, iron-containing slags, ferro-manganese containing slags and mixtures thereof.

48. The feedstock according to any of claims 39 to Claim 47, wherein the reductant is a reductant for reducing the desired metal compound.

49. The feedstock according to any of claims 39 to 41 inclusive, wherein the preferred metal ore comprises 10% to 50% by mass of the feedstock.

50. The feedstock according to any of claims 39 to 49 inclusive, which includes a metal alloying component containing an additional metal to the desired metal and the preferred metal.

51. The feedstock according to Claim 50, wherein the additional metal is iron.

52. The feedstock according to any of claims 39 to 51, wherein the reductant, the ore and at least a part of the metallurgical slag is in solid form.

53. The feedstock according to any of claims 39 to 52 wherein the metallurgical slag is at least partly in molten form.

54. A molten metal produced in accordance with the method of Claim 1.

55. A valuable by-product produced in accordance with the method of any of claims 36 to 38.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/054008

A. CLASSIFICATION OF SUBJECT MATTER

INV. C21B3/04 C22B5/02 C22B5/04 C22B5/06 C22B7/04
C22B47/00 C22C33/04

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21B C22B C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EISSA MAMDOUH ET AL: "Production of high carbon ferromanganese using manganese rich slag in the charge", STEEL RESEARCH, DUESSELDORF, DE, vol. 69, no. 9, 1 September 1998 (1998-09-01), pages 373-380, XP009140574, ISSN: 0177-4832 page 374 - page 379; figures 1-15; tables 1-5	1-55
X	US 3 326 670 A (BRATTON BILLY B) 20 June 1967 (1967-06-20) column 6, line 2 - line 14 column 14, line 54 - line 71	1-55

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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/054008

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2 438 911 A (MARTIN GRONNINGSAETER ANTON) 6 April 1948 (1948-04-06) column 3, line 20 - line 45	1-55
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