FORM 2

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COMPLETE SPECIFICATION

(See Section 10, rule 13)

"A METHOD FOR PRODUCTION OF CLINKER"

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The following specification particularly describes the invention and the manner in which it is to be performed.

TECHNICAL FIELD

The present disclosure is in the field of metallurgy and construction industry. In particular, the present disclosure relates to a method of production of clinker by employing calcium-rich fraction of steel slag as one of the raw materials. More particularly, the method involves dry separation of iron rich and calcium rich fractions of steel slag and further using the calcium rich fraction of steel slag for production of clinker.

BACKGROUND OF THE DISCLOSURE

In general, Portland cements are manufactured from the grounded limestone calcined at high temperature and then cooled to form the required phases such as di-calcium silicate, tri-calcium silicate, calcium aluminate. A small amount of gypsum is mixed with the clinker to produce Portland cement. However, cement production is a highly energy-intensive process. Cement making consists of three main steps: raw material calcination, clinker making in the clinker oven (kiln) and cement making. A large amount of energy is required for the calcination of the raw material and to reach the high temperatures (around 1400^{o}C) required in the kiln. The theoretical energy consumption for producing cement is about 1.76 GJ, estimated based on the energy required to produce 1 ton of Portland cement clinker. In cement plants, besides CO_2 emissions from energy consumption, the cement-making process also emits CO_2 from calcining process thereby substantially increasing carbon footprint from the overall process.

While the prior art has attempted to reduce the energy requirement during the clinker/cement manufacturing, some of the primary limitations of the existing routes for production of cement clinker are as follows:

- high energy consumption,
- high CO_2 emissions during calcination, and
- high iron oxide content in the raw material(s) used for clinker manufacturing.

Hence, there is a need for a simple, economical, environment friendly (low carbon footprint) and energy efficient method for production of cement clinker. The present disclosure tries to address said need.

SUMMARY OF THE DISCLOSURE

The present disclosure relates to a method for manufacturing clinker using calcium rich fraction of steel slag, the method comprising:

a) crushing steel slag to obtain crushed particles;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction;
c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain a mixture; and
d) heating the mixture to produce the clinker.

In some embodiments of the present method, the steel slag is crushed in a jaw crusher, or roll crusher, or high-pressure grinding roll.

In some embodiments of the present method, the crushed particles have a particle size of below 3 mm, including all values and ranges therebetween.

In some embodiments of the present method, the dry separation is selected from magnetic separation, gravity separation, or classification, or any combination thereof.

In some embodiments of the present method, the dry separation is dry magnetic separation.

In some embodiments of the present method, the magnetic separation is carried out at a magnetic field intensity in the range of 0.05 Tesla (T) to 0.15 Tesla (T), including all values and ranges therebetween.

In some embodiments of the present method, the iron-rich fraction and calcium-rich fraction are separated from the crushed particles based on magnetic susceptibility difference.

In some embodiments of the present method, yield of the iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag and yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag.

In some embodiments of the present method, the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud is ground before the mixing in step c).

In some embodiments of the present method, the grinding is carried out in ball mill or high-pressure grinding mill or vertical agitation mill or horizontal mill or vertical roller mill, or any combination thereof.

In some embodiments of the present method, the mixing in step c) comprises mixing calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w), to obtain the mixture.

In some embodiments of the present method, the mixture obtained in step c) has a particle size of less than 106 µm, including all values and ranges therebetween.

In some embodiments of the present method, the mixture is heated to a temperature between 1375^{o}C to 1500^{o}C, including all values and ranges therebetween.

In an exemplary embodiment of the present method, the mixture is heated for a time-period of about 2 hours to 6 hours, including all values and ranges therebetween.

The present disclosure further relates to a process of dry separation of of iron-rich fraction from the calcium rich fraction of the steel slag, wherein separation is preferably carried out by means of a dry magnetic separator and wherein the iron-rich fraction and calcium-rich fraction are separated on the basis of magnetic susceptibility difference.

The present disclosure also relates to a process for producing a raw material mixture for the clinker production, wherein the calcium-rich fraction of steel slag is mixed with limestone, bauxite and red mud to obtain the raw material mixture.

In some embodiments, the process for producing a raw material mixture for the clinker production comprises:

a) crushing steel slag to obtain crushed particles;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction; and

c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain the raw material mixture.

In some embodiments of the process for producing the raw material mixture, the process comprises:

a) crushing steel slag to obtain crushed particles having a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction, wherein the dry separation is dry magnetic separation; and
c) grinding the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud followed by mixing the calcium-rich fraction, the limestone, the bauxite and the red mud to obtain the raw material mixture having a particle size of less than 106 µm or a D_{80} particle size of below 90 µm.

The present disclosure also relates to a a raw material mixture comprising the calcium-rich fraction of steel slag, limestone, bauxite and red mud.

In some embodiments, raw material mixture for production of clinker comprises calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w).

In some embodiments, the calcium-rich fraction of steel slag in the raw material mixture comprises CaO at about 45% to 50% (w/w), $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4% (w/w).

In some embodiments, the raw material mixture has a particle size of less than 106 µm.

BRIEF DESCRIPTION OF THE ACCOMPANYING FIGURES

Figure 1 depicts a flow chart representing an exemplary embodiment of production of clinker according to the present disclosure.

Figure 2 depicts particle phase and element analysis of steel slag using electron microscope (SEM-EDS).

Figure 3 depicts the elemental mapping of steel slag using electron microscope (SEM-EDS).

Figure 4 depicts XRD pattern of clinker with addition of calcium-rich fraction of steel slag (3 wt%) and without addition of calcium-rich fraction of steel slag.

Figure 5 depicts weight loss curve during the Thermo-Gravimetric Analysis (TGA) of the clinker samples (Left: without steel slag; Right: with 10% steel slag).

DETAILED DESCRIPTION OF THE DISCLOSURE

With respect to the use of substantially any plural and/or singular terms herein (such as "a", "an" and "the"), those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity. The various singular/plural permutations may be expressly set forth herein for sake of clarity. The suffix "(s)" at the end of any term in the present disclosure envisages in scope both the singular and plural forms of said term.

The use of the expression "at least" or "at least one" suggests the use of one or more elements or ingredients or quantities, as the use may be in the embodiment of the disclosure to achieve one or more of the desired objects or results. As such, the terms "a" (or "an"), "one or more", and "at least one" can be used interchangeably herein.

Throughout this specification, the word "comprise", or variations such as "comprises" or "comprising" or "containing" or "has" or "having" wherever used, will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Throughout this specification, the term 'combination thereof' or 'combinations thereof' or 'any combination thereof' or 'any combinations thereof' are used interchangeably and are intended to have the same meaning, as regularly known in the field of patents disclosures.

The terms "about" or "approximately" as used herein when referring to a measurable value such as a parameter, an amount, a temporal duration, and the like, are meant to encompass

variations of and from the specified value, such as variations of +/- 10% or less, +/- 5% or less, +/-1% or less, and +/-0.1% or less of and from the specified value, insofar such variations are appropriate to perform in the disclosed invention. It is to be understood that the value to which the modifier "about" or "approximately" refers is itself also specifically, and preferably, disclosed.

As used herein, the term "comprising" when placed before the recitation of steps in a method means that the method encompasses one or more steps that are additional to those expressly recited, and that the additional one or more steps may be performed before, between, and/or after the recited steps. For example, a method comprising steps a, b, and c encompasses a method of steps a, b, x, and c, a method of steps a, b, c, and x, as well as a method of steps x, a, b, and c. Furthermore, the term "comprising" when placed before the recitation of steps in a method does not (although it may) require sequential performance of the listed steps, unless the content clearly dictates otherwise. For example, a method comprising steps a, b, and c encompasses, for example, a method of performing steps in the order of steps a, c, and b, the order of steps c, b, and a, and the order of steps c, a, and b, etc.

As used herein, the term 'clinker' refers to a nodular material produced in the kilning stage during the production of cement and is used as the binder in many cement products. In other words, it is a solid material produced in the manufacture of Portland cement as an intermediary product. Clinker, when added with gypsum (to control the setting properties of cement and ensure compressive strength) and other optional minor constituents, and ground finely, produces cement.

As used herein, the phrase 'cement' or 'Portland cement' is a binder or a substance used for construction that sets, hardens, and adheres to other materials to bind them together. It refers to a fine powder produced by grinding clinker (e.g. more than 90%), a limited amount of gypsum (calcium sulphate dehydrate – $CaSO_4.2H_2O$, which controls the set time) and other minor constituents which can be used to vary the properties of the final cement.

As used herein, the phrase 'steel slag' refers to a by-product of steel making process, which is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is usually a complex solution of silicates and oxides that solidify upon cooling.

As used herein, the phrase ‘BOF’ or ‘Basic Oxygen Furnace’ is a steel making furnace, in which molten pig iron and steel scrap is converted into steel due to oxidizing action of oxygen blown into the melt under a basic slag. During the process, oxygen is blown into a BOF converter containing liquid hot metal having high carbon content. The oxygen combines with the dissolved carbon to form CO, which then escapes as gas. Thus, the hot metal is transformed into liquid steel with a low carbon content in the BOF.

As used herein, the phrase ‘limestone’ refers to a sedimentary rock composed principally of calcium carbonate (calcite) or the double carbonate of calcium and magnesium (dolomite), with minor constituents such as clay, iron carbonate, feldspar, pyrite, and quartz. Exemplary limestone compositions are provided in the forthcoming paragraphs of the present disclosure.

As used herein, the phrase ‘bauxite’ refers to heterogeneous material composed primarily of one or more aluminum hydroxide minerals, plus various mixtures of silica, iron oxide, titania, aluminosilicate, and other impurities in minor or trace amounts. Exemplary bauxite compositions are provided in the forthcoming paragraphs of the present disclosure.

As used herein, the phrase ‘red mud’ is an industrial waste generated during the processing of bauxite into alumina using the Bayer process. It is composed of various oxide compounds, including the iron oxides which give its red colour. Exemplary red mud compositions are provided in the forthcoming paragraphs of the present disclosure.

The present disclosure is in relation to production of clinker.

An objective of the present disclosure is to develop a simple, energy efficient, environment friendly/low carbon footprint process for production of clinker, which can be used in cement manufacturing.

Another objective of the present disclosure is to employ a by-product of steel manufacturing such as steel slag (often regarded as waste) as one of the raw materials for production of clinker.

Another objective of the present disclosure is to employ calcium rich fraction of steel slag along with limestone, bauxite and red mud as a raw material mixture for production of clinker.

Another objective of the present disclosure is to employ steel slag, particularly the calcium rich fraction of steel slag in the production of clinker to reduce the fusion temperature and thereby energy requirement of the process.

Another objective of the present disclosure is to employ calcium rich fraction of steel slag in the production of clinker to reduce the CO_2 emissions of the overall process.

Yet another objective of the present disclosure is to employ the calcium rich fraction for clinker production and iron rich fraction in steel making process, thereby completely utilizing the steel slag (a by-product of steel making process).

Still another objective of the present disclosure is to develop a process for dry separation of iron-rich fraction from the calcium rich fraction of the steel slag.

Another objective of the present disclosure is to develop a process for producing a raw material mixture for the clinker production.

Yet another objective of the present invention is to develop a raw material mixture comprising the calcium-rich fraction of steel slag, limestone, bauxite and red mud, for clinker production.

To achieve the aforesaid objectives, the present disclosure relates to a method for manufacturing clinker by employing a raw material mixture comprising calcium-rich fraction of steel slag, limestone, bauxite and red mud. The clinker produced can be further used in cement manufacturing.

The present disclosure particularly relates to a method for producing clinker comprising heating a raw material mixture comprising: a) calcium-rich fraction of steel slag, b) limestone, c) bauxite and d) red mud, to obtain the clinker;

wherein the calcium-rich fraction of steel slag is obtained by dry separation of steel slag into iron-rich fraction and calcium-rich fraction.

More particularly, the present disclosure provides a method for production of clinker, comprising:

a) crushing steel slag to obtain crushed particles;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction;
c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain a mixture; and
d) heating the mixture to produce the clinker.

In embodiments of the present method, the steel slag comprises CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w), Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%.

In some embodiments of the present method, the steel slag is crushed in a jaw crusher, or roll crusher, or high-pressure grinding roll.

In some embodiments of the present method, the steel slag is basic oxygen furnace (BOF) slag, ladle furnace (LF) slag, electric arc furnace (EAF) slag, or any combination thereof.

In some embodiments of the present method, the crushed particles have a particle size of below 3 mm, including all values and ranges therebetween.

In some embodiments of the present method, the crushed particles have a particle size of about 0.5 mm, about 1 mm, about 1.5 mm, about 2 mm, about 2.5 mm or about 3 mm.

In some embodiments of the present method, the crushed particles have a D_{80} particle size of about 1 mm to 3 mm, including all values and ranges therebetween.

In some embodiments of the present method, the crushed particles have a D_{80} particle size of about 1 mm, about 1.25 mm, about 1.5 mm, about 1.75 mm, about 2 mm, about 2.25 mm, about 2.5 mm, about 2.75 mm, or about 3 mm.

In some embodiments of the present method, the dry separation is selected from magnetic separation, gravity separation, or classification, or any combination thereof.

In some embodiments of the present method, gravity separation refers to an industrial method of separation that relies on different specific gravity of minerals and their relative motion under gravity and drag forces. Gravity separation is used in a wide variety of industries and can be most simply differentiated by the characteristics of the mixture to be separated - principally that of 'wet' i.e. - a suspension versus 'dry'- a mixture of granular product.

In some embodiments of the present method, classification refers to sorting of particulate material into different size ranges. It is a method of separation of fines from coarse particles and also lighter particles from heavier particles. This method is particularly suited for particles finer than 1 mm that are out of the practical range of conventional screens. The principle of classification is based upon the density, specific gravity, terminal falling velocity of particles in liquid and in air.

In some embodiments of the present method, the dry separation is dry magnetic separation.

In some embodiments of the present method, the magnetic separation is carried out at a magnetic field intensity in the range of 0.05 Tesla (T) to 0.15 Tesla (T), including all values and ranges therebetween.

In some embodiments of the present method, the magnetic separation is carried out at a magnetic field intensity of 0.05 T, 0.075 T, 0.10 T, or 0.15 T.

In some embodiments of the present method, the magnetic separation is carried out by means of a dry magnetic separator.

In some embodiments of the present method, the magnetic separation is carried out by means of a dry magnetic separator.

In some embodiments of the present method, the dry magnetic separator is drum dry type low intensity magnetic separator.

In some embodiments of the present method, the magnetic separation is carried out by drum dry type low intensity magnetic separator.

In some embodiments of the present method, the iron-rich fraction and calcium-rich fraction are separated from the crushed particles based on magnetic susceptibility difference.

In some embodiments of the present method, yield of the iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag and yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag.

In some embodiments of the present method, yield of the calcium-rich fraction is in the range of 70% to 88% (w/w), including all values and ranges therebetween, by weight of the steel slag.

In some embodiments of the present method, yield of the iron-rich fraction is in the range of 12% to 30% (w/w), including all values and ranges there between, by weight of the steel slag.

In some embodiments of the present method, yield of the iron-rich fraction is in the range of 12% to 25% (w/w) by weight of the steel slag and yield of the calcium-rich fraction is in the range of 75% to 88% (w/w) by weight of the steel slag.

In some embodiments of the present method, the iron-rich fraction comprises $Fe_{(T)}$ at about 25% to 35% (w/w), FeO at about 14% to 20% (w/w), CaO at about 26% to 38% (w/w), SiO_2 at about 8% to 11% (w/w), Al_2O_3 at about 1% to 2% (w/w), P_2O_5 at about 1.5% to 2.5% (w/w).

In some embodiments of the present method, the iron-rich fraction comprises $Fe_{(T)}$ at about 29.55 % (w/w), FeO at about 17.7% (w/w), CaO at about 36.92% (w/w), SiO_2 at about 10.3% (w/w), Al_2O_3 at about 1.53 % (w/w), P_2O_5 at about 2.4 % (w/w) and other impurities in minor or trace amounts.

In some embodiments of the present method, the calcium-rich fraction comprises $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), CaO at about 45% to 50% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4.0% (w/w).

In some embodiments of the present method, the calcium-rich fraction comprises $Fe_{(T)}$ at about 13.74% (w/w), FeO at about 8.08 % (w/w), CaO at about 47.94 % (w/w), SiO_2 at about 13.9 % (w/w), Al_2O_3 at about 0.57 % (w/w) and P_2O_5 at about 3.55 % (w/w) and other impurities in minor or trace amounts.

In some embodiments of the present method, the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud is ground before the mixing in step c).

In some embodiments of the present method, the calcium-rich fraction of steel slag is ground before the mixing in step c).

In some embodiments of the present method, the calcium-rich fraction of steel slag and one or more of the limestone, the bauxite and the red mud is ground before the mixing in step c).

In some embodiments of the present method, the calcium-rich fraction of steel slag, the limestone, the bauxite and the red mud is ground before the mixing in step c).

In some embodiments of the present method, the grinding is carried out in ball mill or high-pressure grinding mill or vertical agitation mill or horizontal mill or vertical roller mill, or any combination thereof.

In some embodiments of the present method, the grinding is carried out in a ball mill.

In some embodiments of the present method, the mixing in step c) comprises mixing calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w), to obtain the mixture.

In some embodiments of the present method, the mixing in step c) employs calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), including all values and ranges therebetween.

In some embodiments of the present method, the mixing in step c) employs calcium-rich fraction of steel slag preferably in an amount at about 1% to 10% (w/w), or about 2% to 10% (w/w), or about 3% to 10% (w/w), or about 4% to 10% (w/w), or about 5% to 10% (w/w), or about 6% to 10% (w/w), or about 7% to 10% (w/w), or about 8% to 10% (w/w), or about 9% to 10% (w/w).

In some embodiments of the present method, the mixing in step c) employs limestone at about 84% to 95% (w/w), including all values and ranges therebetween.

In some embodiments of the present method, the mixing in step c) employs bauxite at about 2.5% to 4% (w/w), including all values and ranges therebetween.

In some embodiments of the present method, the mixing in step c) employs red mud at about 1.5% to 3% (w/w), including all values and ranges therebetween.

In some embodiments of the present method, the mixing in step c) comprises mixing calcium-rich fraction of steel slag at about 4% to 10% (w/w), limestone at about 88% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w), to obtain the mixture.

In some embodiments of the present method, the limestone comprises CaO at about 45% to 56% (w/w), SiO_2 at about 0.5% to 20% (w/w), $Fe_{(T)}$ at about 0% to 1% (w/w), MgO at about 0.2% to 0.8% (w/w), MnO at about 0.02% to 0.5% (w/w), Al_2O_3 at about 0.5% to 2.0% (w/w), TiO_2 at about 0.01% to 0.05% (w/w), Cr_2O_3 at about 0.005% to 0.008% (w/w), S at about 0.1% to 1.0% (w/w), Na_2O at about 0.001% to 0.005% (w/w), P_2O_5 at about 0.05% to 0.5% (w/w), K_2O at about 0.001% to 0.005% (w/w), loss of ignition at about 25% to 45% (w/w) and moisture at about 0.5% to 3% (w/w).

In some embodiments of the present method, the bauxite comprises CaO at about 25% to 40% (w/w), SiO_2 at about 5% to 15% (w/w), $Fe_{(T)}$ at about 10% to 20% (w/w), MgO at about 0.1% to 0.2% (w/w), MnO at about 0.001% to 0.005% (w/w), Al_2O_3 at about 30% to 42.0% (w/w), TiO_2 at about 3% to 8.0% (w/w), Cr_2O_3 at about 0.05% to 0.1% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 0.05% to 0.08% (w/w), P_2O_5 at about 0.1% to 0.5% (w/w), K_2O at about

0.05% to 0.08% (w/w), loss of ignition at about 20% to 27%(w/w) and moisture at about 1% to 3% (w/w).

In some embodiments of the present method, the red mud comprises CaO at about 2% to 4% (w/w), SiO_2 at about 6% to 9% (w/w), $Fe_{(T)}$ at about 22% to 30% (w/w), MgO at about 0.1% to 0.3% (w/w), MnO at about 0.02% to 0.06% (w/w), Al_2O_3 at about 11% to 18% (w/w), TiO_2 at about 12% to 18% (w/w), Cr_2O_3 at about 0.1% to 0.2% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 3.5% to 8% (w/w), P_2O_5 at about 0.2% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 12% to 20% (w/w), and moisture at about 2% to 5% (w/w).

In some embodiments of the present method, the mixing is carried out in semi-autogenous mill, autogenous mill, rotary mixture, rod mill, pebble mill, rotary mixture, ball mill, high-pressure grinding mill, vertical agitation mill, horizontal mill or vertical roller mill, or any combination thereof.

In some embodiments of the present method, the mixture obtained in step c) has a particle size of less than 106 µm, including all values and ranges therebetween.

In some embodiments of the present method, the mixture obtained in step c) has a particle size of about 80 µm, about 85 µm, about 90 µm, about 95 µm, about 100 µm, about 101 µm, about 102 µm, about 103 µm, about 104 µm, or about 105 µm.

In some embodiments of the present method, the mixture obtained in step c) has a D_{80} particle size of below 90 µm, including all values and ranges therebetween.

In some embodiments of the present method, the mixture obtained in step c) has a D_{80} particle size of about 60 µm, about 65 µm, about 70 µm, about 75 µm, about 80 µm, about 81 µm, about 82 µm, about 83 µm, about 84 µm, about 85 µm, about 86 µm, about 87 µm, about 88 µm, or about 89 µm.

In some embodiments of the present method, the mixture is heated to a temperature between 1375°C to 1500°C, including all values and ranges there between.

In some embodiments of the present method, the mixture is heated to a temperature of about 1375°C, about 1380°C, about 1390°C, about 1400°C, about 1410°C, about 1420°C, about 1430°C, about 1440°C, about 1450°C, about 1460°C, about 1470°C, about 1480°C, about 1490°C, or about 1500°C.

In an exemplary embodiment of the present method, the mixture is heated for a time-period of about 2 hours to 6 hours, including all values and ranges therebetween.

In some embodiments of the present method, the mixture is heated for a time-period of about 2 hours, 2.5 hours, 3 hours, 3.5 hours, 4 hours, 4.5 hours, 5 hours, 5.5 hours, or about 6 hours.

In some embodiments of the present method, the method comprises:

a) crushing steel slag to obtain crushed particles having a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction, wherein the dry separation is dry magnetic separation;
c) grinding the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud followed by mixing the calcium-rich fraction, the limestone, the bauxite and the red mud to obtain a mixture having a particle size of less than 106 µm or a D_{80} particle size of below 90 µm; and
d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

In some embodiments of the present method, the method comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm;
b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction, wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T;
c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D_{80} particle size of below 90 µm; and

d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

In some embodiments of the present method, the method comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm,

wherein the steel slag has a composition comprising CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w), Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%;

b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction,

wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T,

and wherein the yield of iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag, and the yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag;

c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 8% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D_{80} particle size of below 90 µm; and

d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

In some embodiments of the present method, the method comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm,

wherein the steel slag has a composition comprising CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w),

Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%;

b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction,

wherein the dry magnetic separation is carried out in a drum dry type low intensity magnetic separator at a magnetic field intensity in the range of 0.05 T to 0.15 T,

wherein the yield of iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag, and the yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag,

and wherein the calcium-rich fraction comprises $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), CaO at about 45% to 50% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4.0% (w/w), and the iron-rich fraction comprises $Fe_{(T)}$ at about 25% to 35% (w/w), FeO at about 14% to 20% (w/w), CaO at about 26% to 38% (w/w), SiO_2 at about 8% to 11% (w/w), Al_2O_3 at about 1% to 2% (w/w), P_2O_5 at about 1.5% to 2.5% (w/w);

c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D_{80} particle size of below 90 µm; and

d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

In some embodiments of the present method, the method comprises separation of iron rich fraction and calcium-rich fraction from steel slag, and to produce a clinker from a raw material mixture comprising calcium-rich fraction of steel slag, limestone, bauxite and red mud. In some embodiments, the method comprises dry magnetic separation of the crushed steel slag having a particle size of below 3 mm to separate calcium rich fraction and iron rich fraction; followed by grinding of the calcium rich fraction to a particle size of below 106 µm; mixing the calcium rich fraction with limestone, bauxite and red mud to form a raw material mixture; and thereafter subjecting said raw material mixture to heating/temperature treatment to produce clinker.

Further, the present invention provides a clinker product for manufacturing of cement.

In some embodiments, the present invention provides a clinker product produced by the clinker manufacturing method as described above.

In some embodiments, the clinker comprises $Fe_{(T)}$ at about 3% to 3.76% (w/w), CaO at about 64.1% to 65% (w/w), SiO_2 at about 21.2% to 22.2% (w/w), S at about 0.26% to 0.27% (w/w), MgO at about 0.7% to 1.10% (w/w), MnO at about 0.31% to 0.33% (w/w), Al_2O_3 at about 5.0 to 5.5% (w/w), TiO_2 at about 0.92% to 0.94% (w/w), Cr_2O_3 at about 0.02% to 0.03% (w/w), K_2O at about 0.01% to 0.02% (w/w), Na_2O at about 0.22% to 0.23% (w/w), P_2O_5 at about 0.002% to 0.008% (w/w), and Fe_2O_3 at about 0.4 to 0.7% (w/w).

In some embodiments, the clinker comprises $Fe_{(T)}$ at about 0.5% to 4.5% (w/w), CaO at about % 62 to 67% (w/w), SiO_2 at about 20% to 24% (w/w), S at about 0.25% to 0.28% (w/w), MgO at about 0.5% to 1.5% (w/w), MnO at about 0.2% to 0.5% (w/w), Al_2O_3 at about 3.5% to 6% (w/w), TiO_2 at about 0.9% to 0.96% (w/w), Cr_2O_3 at about 0.01% to 0.04% (w/w), K_2O at about 0.01% to 0.02% (w/w), Na_2O at about 0.2% to 0.25% (w/w), P_2O_5 at about 0.001% to 0.01% (w/w), and Fe_2O_3 at about 0.1% to 2% (w/w).

The present invention also provides a process for producing a raw material mixture for the clinker production, said process comprising:

a) crushing steel slag to obtain crushed particles;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction; and
c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain the raw material mixture.

In some embodiments of the process for producing the raw material mixture, the process comprises:

a) crushing steel slag to obtain crushed particles having a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm;
b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction, wherein the dry separation is dry magnetic separation; and
c) grinding the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud followed by mixing the calcium-rich fraction, the

limestone, the bauxite and the red mud to obtain the raw material mixture having a particle size of less than 106 µm or a D_{80} particle size of below 90 µm.

In some embodiments of the process for producing the raw material mixture, the process comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm;
b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction, wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T; and
c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain the raw material mixture having a D_{80} particle size of below 90 µm.

In some embodiments of the process for producing the raw material mixture, the process comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm,

   wherein the steel slag has a composition comprising CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w), Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%;
b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction,

   wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T,

   and wherein the yield of iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag, and the yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag;

c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D80 particle size of below 90 µm;

In some embodiments of the process for producing the raw material mixture, the process comprises:

a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm,

wherein the steel slag has a composition comprising CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w), Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%;

b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction,

wherein the dry magnetic separation is carried out in a drum dry type low intensity magnetic separator at a magnetic field intensity in the range of 0.05 T to 0.15 T,

wherein the yield of iron-rich fraction is in the range of 12% to 30% (w/w) by weight of the steel slag, and the yield of the calcium-rich fraction is in the range of 70% to 88% (w/w) by weight of the steel slag,

and wherein the calcium-rich fraction comprises $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), CaO at about 45% to 50% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4.0% (w/w), and the iron-rich fraction comprises $Fe_{(T)}$ at about 25% to 35% (w/w), FeO at about 14% to 20% (w/w), CaO at about 26% to 38% (w/w), SiO_2 at about 8% to 11% (w/w), Al_2O_3 at about 1% to 2% (w/w), P_2O_5 at about 1.5% to 2.5% (w/w);

c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D80 particle size of below 90 µm.

The present invention further provides a raw material mixture for production of clinker, said mixture comprising calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w).

In some embodiments, raw material mixture comprises the calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), including all values and ranges therebetween.

In some embodiments, raw material mixture comprises calcium-rich fraction of steel slag preferably in an amount at about 1% to 10% (w/w), or about 2% to 10% (w/w), or about 3% to 10% (w/w), or about 4% to 10% (w/w), or about 5% to 10% (w/w), or about 6% to 10% (w/w), or about 7% to 10% (w/w), or about 8% to 10% (w/w), or about 9% to 10% (w/w).

In some embodiments, the calcium-rich fraction of steel slag in the raw material mixture comprises CaO at about 45% to 50% (w/w), $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4% (w/w).

In some embodiments, raw material mixture comprises the limestone at about 84% to 95% (w/w), including all values and ranges therebetween.

In some embodiments, the limestone in the raw material mixture comprises CaO at about 45% to 56% (w/w), SiO_2 at about 0.5% to 20% (w/w), $Fe_{(T)}$ at about 0% to 1% (w/w), MgO at about 0.2% to 0.8% (w/w), MnO at about 0.02% to 0.5% (w/w), Al_2O_3 at about 0.5% to 2.0% (w/w), TiO_2 at about 0.01% to 0.05% (w/w), Cr_2O_3 at about 0.005% to 0.008% (w/w), S at about 0.1% to 1.0% (w/w), Na_2O at about 0.001% to 0.005% (w/w), P_2O_5 at about 0.05% to 0.5% (w/w), K_2O at about 0.001% to 0.005% (w/w), loss of ignition at about 25% to 45% (w/w) and moisture at about 0.5% to 3% (w/w).

In some embodiments, raw material mixture comprises the bauxite at about 2.5% to 4% (w/w), including all values and ranges therebetween.

In some embodiments, the bauxite in the raw material mixture comprises CaO at about 25% to 40% (w/w), SiO_2 at about 5% to 15% (w/w), $Fe_{(T)}$ at about 10% to 20% (w/w), MgO at about

0.1% to 0.2% (w/w), MnO at about 0.001% to 0.005% (w/w), Al_2O_3 at about 30% to 42.0% (w/w), TiO_2 at about 3% to 8.0% (w/w), Cr_2O_3 at about 0.05% to 0.1% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 0.05% to 0.08% (w/w), P_2O_5 at about 0.1% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 20% to 27%(w/w) and moisture at about 1% to 3% (w/w)

In some embodiments, raw material mixture comprises the red mud at about 1.5% to 3% (w/w), including all values and ranges therebetween.

In some embodiments, the red mud in the raw material mixture comprises CaO at about 2% to 4% (w/w), SiO_2 at about 6% to 9% (w/w), $Fe_{(T)}$ at about 22% to 30% (w/w), MgO at about 0.1% to 0.3% (w/w), MnO at about 0.02% to 0.06% (w/w), Al_2O_3 at about 11% to 18% (w/w), TiO_2 at about 12% to 18% (w/w), Cr_2O_3 at about 0.1% to 0.2% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 3.5% to 8% (w/w), P_2O_5 at about 0.2% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 12% to 20% (w/w), and moisture at about 2% to 5% (w/w).

In some embodiments, the raw material mixture has a particle size of less than 106 µm.

In some embodiments, the raw material mixture has a particle size of about 90 µm, about 95 µm, about 100 µm, about 101 µm, about 102 µm, about 103 µm, about 104 µm, or about 105 µm.

In some embodiments, particle size of the raw material mixture comprises 80% passing below particle size in the range of 90-106 µm.

In some embodiments, particle size of the raw material mixture comprises 70% passing below particle size in the range of 80-90µm.

In some embodiments, particle size of the raw material mixture comprises 60% passing below particle size in the range of 80-90 µm.

In some embodiments, particle size of the raw material mixture comprises 50% passing below particle size in the range of 37-45 µm.

In some embodiments, particle size of the raw material mixture comprises 10% passing below particle size in the range of 5-15 µm.

In some embodiments, the raw material mixture has a D_{80} particle size of below 90 µm, including all values and ranges therebetween.

In some embodiments, the raw material mixture has a D_{80} particle size of about 70 µm, about 75 µm, about 80 µm, about 81 µm, about 82 µm, about 83 µm, about 84 µm, about 85 µm, about 86 µm, about 87 µm, about 88 µm, or about 89 µm.

The present disclosure additionally relates to cement comprising the clinker produced by the method described above, and gypsum.

In some embodiments, the cement comprises 45% (w/w) of clinker, 5% (w/w) of gypsum, 50% (w/w) of blast furnace slag.

In some embodiments, each of the chemical compositions of steel slag, calcium-rich fraction of steel slag, iron-rich fraction of steel slag, limestone, bauxite, red mud, raw material, clinker and cement comprising the components/compounds and the respective concentrations/amounts as described herein are such that the total wt% of each composition sums up to 100 %. In some embodiments, in addition to the defined components/compounds, said compositions may comprise additional impurities/elements/compounds in small or negligible amounts which are inherent and result from the raw material quality or processing steps as described herein. Such additional impurities/elements/compounds are not defined herein but is well understood to a person skilled in the art.

Thus, the present disclosure relates to a simple, cost-effective, energy efficient, environment friendly method of preparing clinker wherein the method employs a dry beneficiation process for separating calcium rich fraction and iron rich fraction of the steel slag, and subsequently employing the calcium rich fraction of the steel slag for clinker manufacturing. In particular, the process employs a raw material mixture comprising calcium-rich fraction of steel slag, limestone, bauxite and red mud to produce the clinker. The employment of calcium rich fraction of steel slag for clinker production results in minimum carbonation reaction, which

results in reduction of CO_2 emissions vis-à-vis the CO_2 emissions produced in the conventional calcination/clinker making process. This also results in the reduction of the carbon footprint of the clinker manufacturing process and further opens up the possibility of utilization of low carbon footprint material like calcium rich fraction of steel slag for the production of clinker, and subsequently to manufacture cement.

The addition of calcium rich fraction of steel slag in the raw material mixture along with limestone, bauxite and red mud for clinker production also reduces the fusion temperature of the burden. The clinker is formed by reaching to a fusion point by reacting with the different phases. This results in decreasing the energy requirement in the cement clinker manufacturing process.

Additionally, the present method results in complete and effective utilization of steel slag since the iron rich fraction and the calcium rich fraction separated by dry mode are advantageously utilized. Particularly, the separated calcium rich fraction of the steel slag is employed for production of clinker, and the iron rich fraction (comprising higher FeO content) of the steel slag is recycled for steel making.

Thus, the present method is useful from environment perspective as it ensures safe, effective and complete utilization of steel slag (a by-product/waste of steel making process) in the production of clinker at lower carbon footprint and energy consumption by lowering the melting point of the clinker raw material mixture.

The present invention also envisages a raw material mixture and a process for producing such raw material mixture for the clinker production. Additionally, the present invention further relates to a cement product comprising the clinker produced by method of the present invention.

In an embodiment of the present disclosure, a flow diagram indicative of the present process is shown in Figure 1. The description of the figure allows for a complete and comprehensive understanding of the process. The Figure 1 shows a flow diagram of effective utilization and recycling of steel slag to produce clinker which can be used for the production of Portland cement. Particularly, Figure 1 illustrates the dry separation and recycling process of iron and calcium rich phases of steel slag and employing the calcium rich phase for clinker making

process comprising the steps of crushing the steel slag, magnetic separation of the steel slag, grinding the calcium rich phase, mixing the calcium rich phase with other raw material components including limestone, bauxite and red mud, and heating of the raw material mixture. The steps are detailed as follows:

- The steel slag is fed to crushing unit (2) for reducing the particle size to below 3 mm.
- The crushed particles are collected and fed to a dry low intensity magnetic separator (3) to separate iron-rich fraction/particles (4) and calcium-rich fraction/particles (5).
- The calcium-rich particles (5) are then subjected to grinding (6) and mixing (6) by adding other raw material materials (7) including, limestone, bauxite and red mud to form a raw material mixture.
- The ground and mixed product is further heated in a preheater and clinker making process (8) is performed.
- The product from the clinker making process produces clinker (9), which is used for cement manufacturing.

The present invention primarily comprising the process of preparing clinker for cement manufacturing possesses at least the following advantages:

a) the process employs calcium rich fraction of steel slag which results in minimum carbonation reaction at high temperatures, thereby reducing CO_2 emissions and carbon footprint of the cement clinker manufacturing process,
b) calcium rich fraction of steel slag in the raw material mixture reduces the fusion temperature of the burden which decreases the energy requirement of the cement clinker manufacturing process,
c) effective and complete utilization of the steel slag (a by-product/waste of steel making process) as calcium rich fraction is employed in low carbon foot print cement clinker manufacturing process and iron rich fraction is recycled for manufacturing of steel; thereby avoiding environmental hazard such as storage of these by-products.
d) the present process is simple, economical, energy efficient and eco-friendly method for manufacturing of cement clinker.

It is to be understood that the foregoing descriptive matter is illustrative of the disclosure and not a limitation. While considerable emphasis has been placed herein on the particular features

of this disclosure, it will be appreciated that various modifications can be made, and that many changes can be made in the preferred embodiments without departing from the principles of the disclosure. Those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein. Similarly, additional embodiments and features of the present disclosure will be apparent to one of ordinary skill in art based upon description provided herein.

Descriptions of well-known/conventional methods/steps and techniques are omitted so as to not unnecessarily obscure the embodiments herein. Further, the disclosure herein provides for examples illustrating the above described embodiments, and in order to illustrate the embodiments of the present disclosure certain aspects have been employed. The examples used herein for such illustration are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the following examples should not be construed as limiting the scope of the embodiments herein.

EXAMPLES

EXAMPLE 1:

The present example provides manufacturing method of clinker involving a step of dry separation of iron and calcium rich fractions of steel slag and using the calcium rich fraction of steel slag with other raw materials/components for preparing a raw material mixture for subsequent clinker production.

Before performing the clinker manufacturing method, steel slag analysis was conducted as follows:

Phase and Element analysis of steel slag

The process handles coarse particles/fines of size below 6 mm generated from slag recycling plant. Further, 80% (by weight) of the fines have a particle diameter in the range of 2.5-4.5 mm. The steel slag employed herein is basic oxygen furnace (BOF) steel slag and contains Wustite [Fe_1O_1], Brown millerite (Mg, Si-exchanged) [$Al_{0.665}Ca_2Fe_{1.052}Mg_{0.133}O_5Si_{0.133}$], Dicalcium silicate – alpha [$Ca_2O_4Si_1$], Brown millerite [$Al_{0.55}Ca_2Fe_{1.45}O_5$], Hatrurite [$Ca_3O_5Si_1$], Dicalcium di-Iron(III) oxide [$Ca_2Fe_2O_5$] and others.

To understand the phase composition of steel slag, samples were processed using Scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM-EDS) and the result is shown in Figure 2.

Further, phase mapping of the steel slag sample envisaged that the iron rich fractions/phases are associated with Mg phases and Ca is distributed in all the phases present. Further, phosphorous is distributed majorly with calcium silicate particles but also present with iron phases. The steel slag contains CaO in the range of 40-50% with other elements. The elemental constituents and amounts of the steel slag composition are given in Table 1, as follows:

Table 1. Element analysis of steel slag

Elements/ Compounds	Assay Value (%)
CaO	44.42
SiO_2	12.18
$Fe_{(T)}$	17.48
FeO	11.4
MgO	5.25
MnO	0.49
Al_2O_3	1.80
TiO_2	0.83
Cr_2O_3	0.15
S	0.01
Na_2O	0.06
P_2O_5	2.83
$Fe_{(MET)}$	0.3
K_2O	0.01
loss of ignition (LOI)	7.02
Free-CaO	2.1
Moisture	2.3

The method of clinker production (illustrated in Figure 1) was performed as follows:

a) Crushing of steel slag

The steel slag fines of above-mentioned composition (Table 1) are fed into the crushing unit (2) such as jaw crusher; roll crusher, high pressure grinding roll, etc. to reduce the feed particle size to below 3 mm for better liberation of iron-bearing particles. The product from the crusher i.e., crushed particles are targeted to get a finer particle size distribution of 1.2 mm to 2.5 mm (D_{80} size). During the crushing, maximum finer particle size produced was below 90 µm in the range of 12% to 20% (by wt.).

b) Dry separation of steel slag

The crushed product is subjected to dry low intensity magnetic separator (3) by means of a drum dry type low intensity magnetic separator with magnetic field intensity in the range of 0.05 Tesla (T) to 0.15 Tesla (T) by varying drum revolution speed and feed rate. The separated product is classified with an abundance of iron rich particles (4) in the magnetic fraction and calcium-rich particles (5) in non-magnetic fraction. The yield of the magnetic fraction (4) is in the range of 12-30% by wt. and the yield of the non-magnetic fraction is in the range of 70-88% by wt.

The separated products were analysed. It was found that the iron rich/magnetic fraction (4) comprises $Fe_{(T)}$ at about 25% to 35% (w/w), FeO at about 14% to 20% (w/w), CaO at about 26% to 38% (w/w), SiO_2 at about 8% to 11% (w/w), Al_2O_3 at about 1% to 2% (w/w), and P_2O_5 at about 1.5% to 2.5% (w/w). The iron-rich phase particles can be recycled and utilized for manufacturing steel. Similarly, the non-magnetic fraction (5) is rich with Ca-bearing phases and comprises Fe(T) at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), CaO at about 45% to 50% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4.0% (w/w). In particular, the non-magnetic fraction (5) is rich with Ca-bearing phases and comprises $Fe_{(T)}$ at 13.74% (w/w), FeO at 8.08% (w/w), CaO at 47.94% (w/w), SiO_2 at 13.90% (w/w), Al_2O_3 at 0.57% (w/w) and P_2O_5 at 3.55% (w/w) and other impurities in minor or trace amounts.

c) Preparation of raw material mixture

The calcium rich product (5) (non-magnetic fraction of steel slag) is subjected to grinding (6) in a ball mill or, high pressure grinding roll or vertical roller mill or vertical/horizontal stirred mill to generate ultrafine particles. Also, other ingredients (7) including limestone at 90.2% (w/w), bauxite at 3.3% (w/w) and red mud at 2.4% (w/w) along with the calcium rich

composition of steel slag at 4% (w/w) are mixed (6) at the recited proportions/amounts to prepare a raw material mixture. The quality/chemical composition of the limestone, bauxite and red mud can be varied, and the chemical composition/analysis is given in Table 2.

Table 2. Element analysis of limestone, bauxite and red mud

Elements/ Compounds	Assay Value (%)		
	Limestone	Bauxite	Red mud
CaO	45.78	2.22	2.52
SiO_2	15.06	10.64	8.73
$Fe_{(T)}$	0.895	13.32	27.35
MgO	0.5	0.15	0.12
MnO	0.022	0.001	0.035
Al_2O_3	1.89	38.45	15.78
TiO_2	0.071	5.89	13.76
Cr_2O_3	0.008	0.066	0.11
S	0.183	0.153	0.19
Na_2O	0.001	0.084	5.815
P_2O_5	0.281	0.221	0.385
K_2O	0.001	0.066	0.065
LOI	34.4	22.81	13.42
Moisture	0.5	0.8	2.0

The grounded raw materials (the calcium rich composition of steel slag, limestone, bauxite and red mud) are mixed in the same mill which was employed during the milling or grinding. The step of mixing is important to obtain the uniform composition. The particle size distribution of the mixed ground product, i.e., raw material mixture was below 106 µm and 80% of the particles were below 90 µm (D_{80} size).

d) Heating of raw material mixture

The obtained raw material mixture was subjected to heating by maintaining the maximum temperature up to 1450^oC for a period of 2 to 6 hours. The clinker was formed by reaching to a fusion point by reacting with the different phases. One of the main advantages of adding

calcium rich fraction of steel slag is to reduce the fusion temperature of the burden which will help in decreasing the energy requirement in the process. The fusion characteristics of the steel slag and clinker raw material mixture were analysed in a heating microscope and the findings are given in Table 3.

Table 3. Fusion characteristics of steel slag and raw material mixture used in clinker making process

	Temperature	
Parameters	Steel slag	Raw material mixture
No Change up to	1000^{o}C	1000^{o}C
Expansion	1002 to 1286^{o}C	1002 to 1284^{o}C
Shrinkage	1374 to 1396^{o}C	1380 to 1398^{o}C
Softening/Melting starts at	1374^{o}C	1390^{o}C
Melting range	1385 to 1400^{o}C	1390 to 1410^{o}C
Complete liquefaction at	1420^{o}C	1430^{o}C

The above analysis in Table 3 shows that fusion characteristics of the steel slag is at a lower range as compared to the raw material mixture. The softening of the slag starts at 1374^{o}C which indirectly lowering the softening temperature of the mix after addition of slag.

Analysis of quality of clinker produced

The quality of the produced clinker (9) is analysed in terms of element analysis and different phases are calculated using Bouge's equations:

$$C_3S = 4.071CaO - (7.602\ SiO_2 + 6.718Al_2O_3\ + 1.43\ Fe_2O_3\ )$$
$$C_2S = 2.867\ SiO_2 + 0.7544\ C_3S$$
$$C_3A = 2.65\ Al_2O_3\ + 0.7544\ C_3S$$
$$C_4AF = 3.043\ Fe_2O_3$$

Further, liquid formation in the clinker burden is an important parameter on the economics of the process which is calculated using the below equation:

$$Percent\ Liquid\ (Liquid\ Phase) = 1.13\ C_3A + 1.35\ C_4AF + MgO + Alkalis$$

Amount of CO_2 emission is calculated by using the below equation:

$$Amount\ of\ CO_2\ emission = 0.44(amount\ of\ CaCO_3) + 0.52(amount\ of\ MgCO_3)$$

The produced clinker was found to be matching with the quality requirements of conventional clinker up to addition of 10% of calcium rich fraction of the steel slag. The quality indices of the clinker after addition of calcium rich fraction of steel slag are given in Table 4. Also, it was found that produced clinker (9) is suitable for the cement production. For the confirmation, the hydraulic property of the cement is analyzed, and the results are given in below Table 5. From the Table 5, it is confirmed that the compressive strength of the cement (35.8 N/mm^2) is higher than the ordinary Portland cement (33.5 N/mm^2).

Table 4. Composition and Quality indices of the produced clinker after employing steel slag according to present method

Constituents of clinker	Assay Value range (%)
$Fe_{(T)}$	3.0-3.76
CaO	64.1-65
SiO_2	21.2-22.2
S	0.26-0.27
MgO	0.7-1.10
MnO	0.31-0.33
Al_2O_3	5.0-5.5
TiO_2	0.92-0.94
Cr_2O_3	0.02-0.03
K_2O	0.01-0.02
Na_2O	0.22-0.23
P_2O_5	0.002-0.008
Fe_2O_3	0.4-0.7
$Fe_{(T)}$	4.0-5.5
Clinker Quality Indicators	
Lime saturation factor (LSF)	0.91-0.92
Silica modulus (SM)	2.05-2.32

Alumina modulus (AM)	0.93-1.22
Phase Analysis (%)	
C_3S	54.0-57.0
C_2S	19.0-23.0
C_3A	4.0-6.0
C_4AF	13.0-16.5
Other indicators	
Liquid Formation (%)	26.0-28.0
CO_2 emission (t/t of clinker)	0.38-0.42

Table 5. Hydraulic parameters of the cement manufactured using steel slag in the clinker

Parameters	Values
Normal Consistency	31.2%
Fineness by Dry Sieving	8%
Specific Gravity	2.92
Setting Time	110 min (initial)
	245 min (Final)
Soundness	1 mm
Compressive Strength (in N/mm^2)	
7 days	20.2±0.7
22 days	24.6±0.4
28 days	35.8±0.6

EXAMPLE 2: Preparation of clinker with varying concentrations of calcium rich fraction of steel slag

This experiment was carried out to produce clinker by adding different concentrations of calcium rich fraction of steel slag and was performed as follows:

As mentioned in Fig. 1, the steel slag from BOF was subjected to crushing to below 3 mm. The crushed steel slag is fed to a low intensity magnetic separator to separate iron rich fraction, which can be recycled for the manufacturing of steel. The calcium rich fraction of steel slag is subjected to grinding and mixed with limestone, bauxite and red mud to produce raw material mixture. The mixed proportion of the ingredients of raw material mixture are given in Table 6.

Table 6: Proportions of calcium rich composition of steel slag in raw material mixture for clinker making

Materials	Weight (%)		
	Test 1	Test 2	Test 3
Limestone	93.1	91.2	90.2
Bauxite	3.4	3.3	3.3
Red mud	2.6	2.5	2.5
Steel slag	1	3	4

These three tests are carried out by varying the addition of calcium-rich fraction of steel slag in the raw material mixture to manufacture clinker by treating at a temperature of 1450^0 C.

The particles are generated after the crushing of steel slag in three different batches and are subjected to particle size distribution. It was found that D_{80} particle size of the crushed product of the Tests 1, 2 and 3 are 1.2, 1.5 and 2.1 mm respectively. The crushed slag contained CaO at about 44.4% (w/w), SiO_2 at about 12.18% (w/w), $Fe_{(T)}$ at about 17.48% (w/w), FeO at about 11.4% (w/w), MgO at about 5.25% (w/w), MnO at about 0.49% (w/w), Al_2O_3 at about 1.83% (w/w), TiO_2 at about 0.83% (w/w), S at about 0.1% (w/w), Cr_2O_3 at about 0.15% (w/w), Na_2O at about 0.06% (w/w), P_2O_5 at about 2.3% (w/w), moisture, and 7.02% of LOI (loss on ignition). The sample also contained free-CaO at about 2.1% (w/w).

The crushed particles of steel slag sample were subjected to dry magnetic separation in drum dry type low intensity magnetic separator by varying drum speed and feed rate and by keeping all other parameters constant. The results of the magnetic separation are given in Table 7.

Table 7: Results of the products after the magnetic separation of steel slag

Products	Assay value (%)								
	$Fe_{(T)}$	FeO	$Fe_{(m)}$	CaO	SiO_2	MgO	MnO	Al_2O_3	P_2O_5
Magnetic	29.55	17.7	1.5	36.92	10.3	3.86	0.54	1.53	2.4
Non-magnetic	13.74	8.08	0.10	47.94	13.90	8.69	0.51	0.57	3.55

In all the three clinker tests, the same Ca-rich fraction was used which is obtained from the non-magnetic fraction of the magnetic separation. The mass split in the test was found to be

44.1% as a Ca-rich product in the non-magnetic fraction. The iron content of the separated product in the non-magnetic fraction was 8.08%. The Ca-rich particles/composition in the non-magnetic fraction was subjected to a temperature of 1450^0C for production of clinker for all the three tests and the results are given in Table 8. The clinker product parameters were found desirable for the cement production.

Table 8: Results of the clinkers obtained after mixing of calcium-rich fraction of steel slag at different proportions according to Table 6

Constituents	Test 1	Test 2	Test 3
	Assay value (%)		
$Fe_{(T)}$	3.14	3.39	3.51
CaO	64.77	64.53	64.41
SiO_2	22.05	21.84	21.73
S	0.27	0.27	0.27
MgO	0.78	0.90	0.96
MnO	0.31	0.32	0.32
Al_2O_3	5.21	5.14	5.10
TiO_2	0.94	0.93	0.93
Cr_2O_3	0.02	0.02	0.02
K_2O	0.01	0.01	0.01
Na_2O	0.23	0.22	0.22
P_2O_5	0.00	0.00	0.00
Fe_2O_3	0.46	0.54	0.57
$Fe_{(T)}$	4.49	4.84	5.02
Lime saturation factor (LSF)	0.91	0.92	0.92
Silica modulus (SM)	2.27	2.19	2.15
Alumina modulus (AM)	1.16	1.06	1.02
C_3S	54.62	55.27	55.59
C_2S	22.02	20.91	20.37
C_3A	6.22	5.43	5.03
C_4AF	13.66	14.74	15.27

Liquid formation (%)	26.5	27.5	27.5
CO_2 emission (t/t of clinker)	0.409	0.401	0.397

Further to confirm, the clinker sample produced by the method of the present invention with calcium fraction of steel slag and without addition of calcium fraction of steel slag was compared and analyzed in terms of XRD patterns as shown in Figure 4. The identical XRD patterns can be observed for both the clinkers, which is evident that the formation of phases are similar to each other.

Also, there is evidence of reduction of weight loss during the Thermo-gravimetric Analysis (TGA) as shown in Figure 5. This indicates that indirectly the presence of the steel slag reduces the activity of the decarbonization process, which is higher in clinker without steel slag.

Thus, the clinker produced by the method of present invention has desirable quality for cement manufacturing along with possessing additional advantages such as reduced CO_2 emissions, energy efficiency, economical use of steel slag (by-product/waste of steel making process), recycling of iron-rich fraction of steel slag back to steel making process etc. as discussed above.

Reference throughout this specification to “some embodiments”, “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment may be included in at least one embodiment of the present disclosure. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification may not necessarily all refer to the same embodiment. It is appreciated that certain features of the disclosure, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the disclosure, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination.

As regards the embodiments characterized in this specification, it is intended that each embodiment be read independently as well as in combination with another embodiment. For example, in case of an embodiment 1 reciting 3 alternatives A, B and C, an embodiment 2 reciting 3 alternatives D, E and F and an embodiment 3 reciting 3 alternatives G, H and I, it is

to be understood that the specification unambiguously discloses embodiments corresponding to combinations A, D, G; A, D, H; A, D, I; A, E, G; A, E, H; A, E, I; A, F, G; A, F, H; A, F, I; B, D, G; B, D, H; B, D, I; B, E, G; B, E, H; B, E, I; B, F, G; B, F, H; B, F, I; C, D, G; C, D, H; C, D, I; C, E, G; C, E, H; C, E, I; C, F, G; C, F, H; C, F, I, unless specifically mentioned otherwise.

Numerical ranges stated in the form 'from x to y' include the values mentioned and those values that lie within the range of the respective measurement accuracy as known to the skilled person. If several preferred numerical ranges are stated in this form, of course, all the ranges formed by a combination of the different end points are also included.

As used herein, the terms "include" (any form of "include", such as "include"), "have" (and "have"), "comprise" etc. any form of "having", "including" (and any form of "including" such as "including"), "containing", "comprising" or "comprises" are inclusive and will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Any discussion or reference of documents, acts, materials, devices, articles and the like that has been included in this specification is solely for the purpose of providing a context for the disclosure. It is not to be taken as an admission that any or all of these matters form a part of the prior art base or were common general knowledge in the field relevant to the disclosure as it existed anywhere before the priority date of this application. Particularly, mention of any reference, article, publication, patent, patent publication, and patent application cited herein is not, and should not be taken as, an acknowledgment or any form of suggestion that they constitute valid prior art or form part of the common general knowledge in any country in the world.

We Claim:

1. A method for production of clinker, comprising:
   a) crushing steel slag to obtain crushed particles;
   b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction;
   c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain a mixture; and
   d) heating the mixture to produce the clinker.

2. The method as claimed in claim 1, wherein the steel slag is basic oxygen furnace (BOF) slag, ladle furnace (LF), electric arc furnace (EAF) slag, or any combination thereof.

3. The method as claimed in claim 1, wherein the steel slag comprises CaO at about 40% to 50% (w/w), $Fe_{(T)}$ at about 15% to 20% (w/w), FeO at about 5% to 15% (w/w), Fe metal at about 0% to 0.5% (w/w), SiO_2 at about 10% to15% (w/w), Al_2O_3 at about 1% to 3% (w/w), MgO at about 2% to 7% (w/w), P_2O_5 at about 1 to 3% (w/w), TiO_2 at about 0.5% to 1% (w/w), Cr_2O_3 at about 0.1% to 0.15% (w/w), S at about 0.05 to 0.15% (w/w), Na_2O at about 0.03% to 0.08% (w/w), K_2O at about 0.01% to 0.03% (w/w), free-CaO at about 2.0% to 3.5%, loss of ignition at about 4% to 9% and moisture at about 1% to 4%.

4. The method as claimed in claim 1, wherein the steel slag in step a) is crushed in a jaw crusher, a roll crusher, or high-pressure grinding roll, or any combination thereof.

5. The method as claimed in claim 1, wherein the crushed particles in step a) have a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm.

6. The method as claimed in claim 1, wherein the dry separation is selected from magnetic separation, gravity separation, or classification, or any combination thereof, preferably magnetic separation.

7. The method as claimed in claim 6, wherein the magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T.

8. The method as claimed in claim 6, wherein the magnetic separation is carried out by means of a dry magnetic separator, wherein the dry magnetic separator is drum dry type low intensity magnetic separator;

and wherein the iron-rich fraction and calcium-rich fraction are separated from the crushed particles based on magnetic susceptibility difference.

9. The method as claimed in claim 1, wherein yield of the iron-rich fraction in step b) is in the range of 12% to 30% by weight of the steel slag.

10. The method as claimed in claim 1, wherein the iron-rich fraction in step b) comprises $Fe_{(T)}$ at about 25% to 35% (w/w), FeO at about 14% to 20% (w/w), CaO at about 26% to 38% (w/w), SiO_2 at about 8% to 11% (w/w), Al_2O_3 at about 1% to 2% (w/w), free lime at about 1% to 3% (w/w), and P_2O_5 at about 1.5% to 2.5% (w/w).

11. The method as claimed in claim 1, wherein yield of the calcium-rich fraction in step b) is in the range of 70% to 88% by weight of the steel slag.

12. The method as claimed in claim 1, wherein the calcium-rich fraction in step b) comprises $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), CaO at about 45% to 50% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w), and P_2O_5 at about 2.8% to 4.0% (w/w).

13. The method as claimed in claim 1, wherein the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud is ground before the mixing in step c);

and wherein the grinding is carried out in ball mill or high-pressure grinding mill or vertical agitation mill or horizontal mill or vertical roller mill, or any combination thereof.

14. The method as claimed in claim 1, wherein the mixing in step c) comprises mixing calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w), to obtain the mixture.

15. The method as claimed in claim 1, wherein the limestone comprises CaO at about 45% to 56% (w/w), SiO_2 at about 0.5% to 20% (w/w), $Fe_{(T)}$ at about 0% to 1% (w/w), MgO at about 0.2% to 0.8% (w/w), MnO at about 0.02% to 0.5% (w/w), Al_2O_3 at about 0.5% to 2.0% (w/w), TiO_2 at about 0.01% to 0.05% (w/w), Cr_2O_3 at about 0.005% to 0.008% (w/w), S at about 0.1% to 1.0% (w/w), Na_2O at about 0.001% to 0.005% (w/w), P_2O_5 at about 0.05% to 0.5% (w/w), K_2O at about 0.001% to 0.005% (w/w), loss of ignition at about 25% to 45% (w/w) and moisture at about 0.5% to 3% (w/w);

the bauxite comprises CaO at about 25% to 40% (w/w), SiO_2 at about 5% to 15% (w/w), $Fe_{(T)}$ at about 10% to 20% (w/w), MgO at about 0.1% to 0.2% (w/w), MnO at about 0.001% to 0.005% (w/w), Al_2O_3 at about 30% to 42.0% (w/w), TiO_2 at about 3% to 8.0% (w/w), Cr_2O_3 at about 0.05% to 0.1% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 0.05% to 0.08% (w/w), P_2O_5 at about 0.1% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 20% to 27%(w/w) and moisture at about 1% to 3% (w/w);

and

the red mud comprises CaO at about 2% to 4% (w/w), SiO_2 at about 6% to 9% (w/w), $Fe_{(T)}$ at about 22% to 30% (w/w), MgO at about 0.1% to 0.3% (w/w), MnO at about 0.02% to 0.06% (w/w), Al_2O_3 at about 11% to 18% (w/w), TiO_2 at about 12% to 18% (w/w), Cr_2O_3 at about 0.1% to 0.2% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 3.5% to 8% (w/w), P_2O_5 at about 0.2% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 12% to 20% (w/w), and moisture at about 2% to 5% (w/w).

16. The method as claimed in claim 1, wherein the mixing in step c) is carried out in semi-autogenous mill, autogenous mill, rotary mixture, rod mill, pebble mill, ball mill, high-pressure grinding mill, vertical agitation mill, horizontal mill or vertical roller mill, or any combination thereof.

17. The method as claimed in claim 11, wherein the mixture obtained in step c) has a particle size of less than 106 µm or a D_{80} particle size of below 90 µm.

18. The method as claimed in claim 1, wherein the mixture in step d) is heated to a temperature between 1375°C to 1500°C.

19. The method as claimed in claim 1, wherein the mixture in step d) is heated to a time-period of about 2 hours to 6 hours.

20. The method as claimed in any of the preceding claims 1-19, wherein the method comprises:
    a) crushing steel slag to obtain crushed particles having a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm;
    b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction, wherein the dry separation is dry magnetic separation;
    c) grinding the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud followed by mixing the calcium-rich fraction, the limestone, the bauxite and the red mud to obtain a mixture having a particle size of less than 106 µm or a D_{80} particle size of below 90 µm; and
    d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

21. The method as claimed in any of the preceding claims 1-20, wherein the method comprises:
    a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm;
    b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich fraction, wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T;
    c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain a mixture having a D_{80} particle size of below 90 µm; and
    d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

22. A clinker produced by the method as claimed in any of the claims 1-21.

23. The clinker as claimed in claim 22, wherein the clinker comprises $Fe_{(T)}$ at about 3% to 3.76% (w/w), CaO at about 64.1% to 65% (w/w), SiO_2 at about 21.2% to 22.2% (w/w), S at about 0.26% to 0.27% (w/w), MgO at about 0.7% to 1.10% (w/w), MnO at about 0.31% to 0.33% (w/w), Al_2O_3 at about 5.0% to 5.5% (w/w), TiO_2 at about 0.92% to 0.94% (w/w), Cr_2O_3 at about 0.02% to 0.03% (w/w), K_2O at about 0.01% to 0.02% (w/w), Na_2O at about 0.22% to 0.23% (w/w), P_2O_5 at about 0.002% to 0.008% (w/w), and Fe_2O_3 at about 0.4% to 0.7% (w/w).

24. A process for producing a raw material mixture for the clinker production method as claimed in claim 1, said process comprising:
    a) crushing steel slag to obtain crushed particles;
    b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction; and
    c) mixing the calcium-rich fraction, limestone, bauxite and red mud to obtain the raw material mixture.

25. The process as claimed in claim 24, wherein the process comprises:
    a) crushing steel slag to obtain crushed particles having a particle size of below 3 mm or a D_{80} particle size of about 1 mm to 3 mm;
    b) subjecting the crushed particles to dry separation to obtain an iron-rich fraction and a calcium-rich fraction, wherein the dry separation is dry magnetic separation; and
    c) grinding the calcium-rich fraction of steel slag and optionally one or more of the limestone, the bauxite and the red mud followed by mixing the calcium-rich fraction, the limestone, the bauxite and the red mud to obtain the raw material mixture having a particle size of less than 106 µm or a D_{80} particle size of below 90 µm.

26. The method as claimed in claim 24 or claim 25, wherein the method comprises:
    a) crushing steel slag to obtain crushed particles having a D_{80} particle size of about 1.2 mm to 2.5 mm;
    b) subjecting the crushed particles to dry magnetic separation to obtain a magnetic fraction as an iron-rich fraction and a non-magnetic fraction as a calcium-rich

fraction, wherein the dry magnetic separation is carried out at a magnetic field intensity in the range of 0.05 T to 0.15 T; and

c) grinding the calcium-rich fraction, followed by mixing the ground calcium-rich fraction at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w) and red mud at about 1.5% to 3% (w/w) to obtain the raw material mixture having a D_{80} particle size of below 90 µm.

d) heating the mixture to a temperature between 1375°C to 1500°C for a time-period of about 2 hours to 6 hours to produce the clinker.

27. A raw material mixture for production of clinker by the method as claimed in claim 1, said mixture comprising calcium-rich fraction of steel slag at about 0.1% to 10% (w/w), limestone at about 84% to 95% (w/w), bauxite at about 2.5% to 4% (w/w), and red mud at about 1.5% to 3% (w/w).

28. The mixture as claimed in claim 27, wherein the calcium-rich fraction of steel slag comprises CaO at about 45% to 50% (w/w), $Fe_{(T)}$ at about 12% to 16% (w/w), FeO at about 5% to 9% (w/w), SiO_2 at about 10% to 14% (w/w), Al_2O_3 at about 0.5% to 1.6% (w/w) and P_2O_5 at about 2.8% to 4% (w/w);

the limestone comprises CaO at about 45% to 56% (w/w), SiO_2 at about 0.5% to 20% (w/w), $Fe_{(T)}$ at about 0% to 1% (w/w), MgO at about 0.2% to 0.8% (w/w), MnO at about 0.02% to 0.5% (w/w), Al_2O_3 at about 0.5% to 2.0% (w/w), TiO_2 at about 0.01% to 0.05% (w/w), Cr_2O_3 at about 0.005% to 0.008% (w/w), S at about 0.1% to 1.0% (w/w), Na_2O at about 0.001% to 0.005% (w/w), P_2O_5 at about 0.05% to 0.5% (w/w), K_2O at about 0.001% to 0.005% (w/w), loss of ignition at about 25% to 45% (w/w) and moisture at about 0.5% to 3% (w/w);

the bauxite comprises CaO at about 25% to 40% (w/w), SiO_2 at about 5% to 15% (w/w), $Fe_{(T)}$ at about 10% to 20% (w/w), MgO at about 0.1% to 0.2% (w/w), MnO at about 0.001% to 0.005% (w/w), Al_2O_3 at about 30% to 42.0% (w/w), TiO_2 at about 3% to 8.0% (w/w), Cr_2O_3 at about 0.05% to 0.1% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 0.05% to 0.08% (w/w), P_2O_5 at about 0.1% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 20% to 27%(w/w) and moisture at about 1% to 3% (w/w); and

the red mud comprises CaO at about 2% to 4% (w/w), SiO_2 at about 6% to 9% (w/w), $Fe_{(T)}$ at about 22% to 30% (w/w), MgO at about 0.1% to 0.3% (w/w), MnO at

about 0.02% to 0.06% (w/w), Al_2O_3 at about 11% to 18% (w/w), TiO_2 at about 12% to 18% (w/w), Cr_2O_3 at about 0.1% to 0.2% (w/w), S at about 0.1% to 0.3% (w/w), Na_2O at about 3.5% to 8% (w/w), P_2O_5 at about 0.2% to 0.5% (w/w), K_2O at about 0.05% to 0.08% (w/w), loss of ignition at about 12% to 20% (w/w), and moisture at about 2% to 5% (w/w).

29. The mixture as claimed in claim 27, wherein the raw material mixture has a particle size of less than 106 µm or a D_{80} particle size of below 90 µm.

30. A cement comprising the clinker as claimed in claim 22, and gypsum along with or without blast furnace slag.

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To:
The Controller of Patents,
The Patent Office, at: Kolkata

“A METHOD FOR PRODUCTION OF CLINKER”

ABSTRACT

The present disclosure provides a simple, economical, environment friendly and energy efficient method for manufacturing clinker using a raw material mix comprising calcium-rich fraction of steel slag, limestone, bauxite and red mud. The method involves dry separation of iron and calcium rich fractions of steel slag and employing the calcium rich fraction of steel slag with other raw materials/components for preparing said raw material mixture for clinker manufacturing. The disclosure provides a simple, economical, environment friendly (low carbon footprint) and energy efficient method for production of cement clinker.