DESCRIPTION

ADMIXTURE, PRODUCTION METHOD OF ADMIXTURE, CONCRETE, PRODUCTION METHOD OF CONCRETE, AND PRODUCTION METHOD OF CALCIUM-CONTAINING MATERIAL

Technical Field

[0001]

The present invention relates to a mineral admixture for concrete and a method of producing the same, concrete containing a mineral admixture and a method of producing the same, and a method of producing a calcium-containing material.

Background Art

[0002]

Carbon dioxide (CO_2), one cause of global warming, generates in the production of cement. Cement is powder that reacts with water to harden, and is used to produce mortar, concrete, and the like. To reduce generation of CO_2, it has been proposed that concrete be produced using blast-furnace slag, fly ash, or the like instead of cement.

[0003]

Another known concrete is produced by using calcium carbonate ($CaCO_3$), biocarbon, or the like as a CO_2-fixed material to reduce CO_2 generated in a production process, to substantially zero or less (see, e.g., Patent Literature 1).

[0004]

Concrete that contains $CaCO_3$ has been traditionally investigated, and can be produced by utilizing conventional technologies. However, calcination of limestone in the production of $CaCO_3$ requires a large amount of energy, and such calcination generates CO_2 although CO_2 is fixed at a process of converting quicklime (CaO) produced by the calcination into $CaCO_3$.

[0005]

Hence, it has been proposed that a material produced by supplying carbon dioxide to calcium components contained in concrete sludge generated in a ready-mixed concrete plant or the like be used as $CaCO_3$, instead of a material derived by calcination of limestone (see, e.g., Patent Literatures 2 and 3). Another proposal is to use a material produced by supplying waste gas from a factory, atmospheric CO_2,

or the like to calcium-containing waste seawater obtained after producing magnesium hydroxide from seawater (see e.g., Patent Literature 3).

Citation List

Patent Literature

[0006]

[Patent Literature 1] Japanese Patent Application Publication No. 2023-160056

[Patent Literature 2] Japanese Patent Application Publication No. 2023-96668

[Patent Literature 3] Japanese Patent Application Publication No. 2023-127648

Summary of Invention

Technical Problem

[0007]

The calcium sources described in Patent Literatures 2 and 3 are derived from waste, but have had the drawback of requiring a dedicated facility for fixing CO_2 in a specific plant such as a ready-mixed concrete plant or a magnesium production plant.

Solution to Problem

[0008]

The present invention was made in consideration of the problems described above and provides a mineral admixture for concrete, the mineral admixture being produced by reacting a by-product obtained in a step of producing quicklime with water and carbon dioxide, and containing 5% by mass or more and 37% by mass or less of calcium.

[0009]

Also provided is a method of producing a mineral admixture for concrete, the mineral admixture containing 5% by mass or more and 37% by mass or less of calcium, and the method including a first step of providing, as a raw material, a by-product obtained in a step of producing quicklime, and reacting the raw material with water, and a second step of reacting a product thus obtained by the first step with carbon dioxide.

Advantageous Effects of Invention

[0010]

The present invention can eliminate the need for a dedicated facility for

fixing CO_2.

Brief Description of Drawings

[0011]

Fig. 1 illustrates steps for producing quicklime.

Fig. 2 shows powder of and calcined dust from a CaO product.

Fig. 3 depicts an exemplary configuration of an apparatus for producing calcium carbonate from quicklime.

Fig. 4 illustrates an exemplary production flow of a mineral admixture for concrete.

Fig. 5 shows a relationship between sieve opening and percentage passing by mass.

Fig. 6 illustrates an exemplary production flow of concrete.

Description of Embodiments

[0012]

Quicklime (calcium oxide: CaO) is obtained by calcining limestone, and utilized for steel, soil amendment, desiccants, raw materials of building materials, and the like. Limestone is mainly formed of calcium carbonate ($CaCO_3$), degrades at about 900°C, releases carbon dioxide (CO_2), and generates CaO.

[0013]

A production step of CaO will now be described with reference to Fig. 1. Limestone dug from a mountain or the like is finely crushed with a crusher at step 100. At step 101, the crushed limestone is classified with a sieve. At step 102, the classified limestone is charged into a furnace, and calcined at 900 to 1000°C. In the calcination of the limestone, the reaction of the following formula (1) occurs to generate quicklime.

$$CaCO_3 \rightarrow CaO + CO_2 \quad (1)$$

[0014]

Quicklime has varied reactivity, characteristics, and other properties, because limestone has a different composition, crystal structure, and the like depending on a place of mining, and also because a condition of tightening by firing, which represents contraction of volume, varies corresponding to a calcination method. A calcination method varies corresponding to, e.g., the type of a furnace for calcining limestone. The type of a furnace is determined by a way of heat exchange between limestone and combustion gas generated by burning fuel such as

heavy oil, and examples thereof include upright furnaces such as Maerz furnaces and Beckenbach furnaces, and horizontal furnaces such as rotary kilns.

[0015]

A Maerz furnace is formed of two furnace cylinders the lower parts of which are connected by a path. Limestone is filled alternately into each of the two furnace cylinders from the top of the furnace, subjected to repeated operation of calcination in one furnace cylinder during preheating of the other furnace cylinder, passed through a cooling zone located at the lower part, and discharged as quicklime from the bottom of the furnace.

[0016]

A Beckenbach furnace is formed of an outer cylinder and an inner cylinder inserted therein. Limestone is filled between the inner cylinder and the outer cylinder from the top of the furnace, passed through a preheating zone, a calcining zone, and a cooling zone, and discharged as quicklime from the bottom of the furnace.

[0017]

A Rotary kiln has a preheating part, a calcining part, and a cooling part, and performs preheating to a thermal decomposition starting temperature in the preheating part, followed by calcination along with transfer by gentle declination and rotation in the calcining part to generate quicklime that is then passed through the cooling part and discharged out of the furnace.

[0018]

Limestone contains calcium carbonate as a main component, and also contains aluminum oxide (Al_2O_3), iron oxide(Fe_2O_3), silica (SiO_2), and the like as other components.

[0019]

In a step of calcining limestone in a process of producing quicklime, a by-product is generated in association with production of quicklime that is to be a product. The by-product is, e.g., calcined dust that is microparticles floating inside a furnace, and collected with, e.g., a dust collecting apparatus such as a bag filter. Calcined dust contains microparticles of CaO generated according to the aforementioned formula (1) from limestone powdered through charging into a furnace, friction with a furnace, and other events and then calcined.

[0020]

For example, in a Beckenbach furnace, limestone is calcined by combustion of cokes through mixing limestone and lump coke and supplying them into the furnace, for the purpose of reduction of fuel cost. Coke contains ash contents such

as Al_2O_3, Fe_2O_3, SiO_2, CaO, and magnesium oxide (MgO), and such ash contents are left after combustion. The ash contents not only adhere to CaO generated by calcination, but also adhere to microparticles of CaO that forms remaining dust, disperse in exhaust gas, remain within a furnace, or are discharged from the bottom of a furnace, and typically are dealt with by surface and separation treatment (Reference 1: Fujio, Michitaka. "Operative Technology for the Beckenbach Lime Shaft Kiln (RSO), Journal of the Society of Inorganic Materials, Japan 7, 220-226 (2000)). These form a by-product or calcined dust that is obtained in a step of producing limestone.

[0021]

Calcined dust is powder containing not only microparticles of CaO but also ash content and the like, and thus displays a brown, gray, black, or another color in contrast to a CaO product that exhibits white. The color varies corresponding to the type of furnace, a component in fuel, and the like, and is one of colors defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors) such as sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, or black.

[0022]

Additionally, in JIS Z 8102: 2001, the common colors listed above are permitted to be designated with modifier names using the terms defined in Table 3 in Definition 7.2 and Table 4 in Definition 7.3, and any of names of the common color listed above also includes a color modified by "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium", defined in Table 3 in Definition 7.2 and Table 4 in Definition 7.3 in JIS Z 8102: 2001 (Definition 11.2, Table 3 in Definition 7.2 and Table 4 in Definition 7.3 in JIS Z 8102: 2001).

[0023]

Fig. 2 shows a color of CaO as a product and a color of calcined dust. Fig. 2(a) shows powder of CaO as a product, the color of which is white. Fig. 2(b) shows calcined dust, which is gray in color.

[0024]

Calcined dust contains CaO, which is nevertheless present in a small content and does not display a certain color, and thus represents waste Ca

components containing CaO and is usually discarded.

[0025]

The following shows the results of fluorescent X-ray analysis and measurement of a particle size distribution of calcined dust obtained by calcining limestone with a Beckenbach furnace. The fluorescent X-ray analysis was performed using the fluorescent X-ray analysis apparatus ZSX Primus II (manufactures by Rigaku Holdings Corporation).

[0026]

The results of fluorescent X-ray analysis showed that the main components were 48.2% by mass of oxygen, 29.9% by mass of calcium, 10.4% by mass of carbon, 4.8% by mass of silicon (silica), and 4.1% by mass of aluminum. Other components of the calcined dust were 0.9% by mass of sulfur, 0.6% by mass of iron, 0.3% by mass of magnesium, 0.2% by mass of titanium, 0.2% by mass of sodium, and the like.

[0027]

The particle size distribution was measured using a laser diffraction/scattering particle diameter distribution measuring device (manufactured by Beckman Coulter Inc.; LS 13 320XR; with a universal liquid module and a wet measuring unit; dispersion media: ion-exchanged water; on a particle diameter basis and a volume basis). Then, a cumulative fraction value on a volume basis was calculated for particles having a particle diameter equal to or less than a predetermined value. As measured by laser diffraction/scattering, the cumulative fraction value of particles having a particle diameter of 600 μm or less on a volume basis was 99.0%, the cumulative fraction value of particles with a particle diameter of 150 μm or less was 79.3%, and the cumulative fraction value of particles with a particle diameter of 75 μm or less was 60.8%.

[0028]

In the by-product or calcined dust in the present invention, which is obtained in a step of producing quicklime, the cumulative fraction value of particles with a particle diameter of 600 μm or less on a volume basis as measured by laser diffraction/scattering may be 70% or more, and further, is preferably 75% or more, 80% or more, 85% or more, 90% or more, 95% or more, or 97% or more.

[0029]

The cumulative fraction value of particles with a particle diameter of 150 μm or less on a volume basis as measured by laser diffraction/scattering may be 50% or more, or may be 55% or more, 60% or more, 65% or more, 70% or more, or 75% or more. The upper limit value may be 95% or less, 90% or less, or 85% or less.

[0030]

The cumulative fraction value of particles with a particle diameter of 75 μm or less on a volume basis as measured by laser diffraction/scattering may be 30% or more, or may be 35% or more, 40% or more, 45% or more, 50% or more, 55% or more. The upper limit value may be 95% or less, 90% or less, 85% or less, 80% or less, 75% or less, 70% or less, or 65% or less.

[0031]

Meanwhile, the qualities of commercially-available industrial limes (CaO) are defined in Japanese Industrial Standards (JIS) R9001: 2006. In JIS R9001: 2006, Special Grade represents a CaO content of 93% by mass or more, Grade 1 represents a CaO content of 90% by mass or more, and Grade 2 represents a CaO content of 80% by mass or more. Even when the CaO content is 80% by mass or more, the Ca content is more than 57% by mass.

[0032]

Production of Grade 1 quicklime needs production of quicklime with a CaO content of 90% by mass or more and a Ca content of more than 64% by mass, and further, production of Special Grade quicklime needs production of quicklime with a CaO content of 93% by mass or more and a Ca content of more than 66% by mass. Therefore, production of quicklime satisfying any of the grades needs production of quicklime with a CaO content of 93% by mass or more and a Ca content of 66% by mass.

[0033]

By contrast, a by-product or calcined dust obtained in a step of producing quicklime may have a Ca content of 57% by mass or less in fluorescent X-ray analysis. Furthermore, in production of Grade 1 quicklime, the by-product or calcined dust may be 64% by mass or less. Additionally, in production of Special Grade quicklime, a by-product or calcined dust may have a Ca content of 66% by mass or less . Therefore, a by-product or calcined dust may not have a CaO content of 93% by mass or more and a Ca content of more than 66% by mass, which satisfy any of the grades.

[0034]

In the by-product or calcined dust in the present invention, which is obtained in a step of producing quicklime, the Ca content by fluorescent X-ray analysis may be 66% by mass or less, 64% by mass or less, 62% by mass or less, 60% by mass or less, 59% by mass or less, 57% by mass or less, less than 57% by mass, 56% by mass or less, 55% by mass or less, 50% by mass or less, 48% by mass or less, 45% by mass or less, 40% by mass or less, or 35% by mass or less. The lower limit value thereof

is preferably 5% by mass or more, 10% by mass or more, or 15% by mass or more, more preferably 20% by mass or more, or 25% by mass or more.

[0035]

In addition, commercially-available industrial lime (CaO) has a sieve permeability of 100% to pass through a sieve with an opening size of 600 μm, and a sieve permeability of 95% or more to pass through a sieve with an opening size of 150 μm.

[0036]

These suggest that a by-product or calcined dust has a Ca content less than the Ca content in commercially-available industrial lime (CaO).

[0037]

From another perspective, concrete is produced by measuring cement, water, aggregate, and the like at a predetermined ratio, charging and kneading them in a concrete mixer. For the production of concrete, a chemical admixture such as a water-reducing agent or a set accelerating agent is optionally added.

[0038]

Cement is produced by charging raw materials such as limestone, clay, silica stone, and iron in a calcination kiln such as a rotary kiln, calcining them at a temperature of about 1500°C followed by rapid cooling, thereby making a calcined mass referred to as clinker, then adding gypsum to the clinker and performing pulverization.

[0039]

In the calcination for making clinker, CO_2 is generated according to the aforementioned formula (1), and a large amount of fuel is burnt for raising a calcination temperature to about 1500°C and generates a large amount of CO_2. CO_2 is one of greenhouse effect gases, which cause global warming, and is required to be reduced in emission. To solve this problem, CO_2 absorption concrete, which absorbs and hardens CO_2, has drawn attention. The use of this technology can achieve so-called carbon negative, in which CO_2 absorption exceeds CO_2 emissions.

[0040]

To achieve carbon negative, it is necessary to use a material that can adsorb or absorb CO_2, such as a CaO-containing material.

[0041]

In addition, absorption of CO_2 is achieved by a hydration reaction that is a reaction with water according to the following formula (2), and a carbonation reaction that is a reaction with carbon dioxide according to the following formula (3).

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (2)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (3)$$

[0042]

Conventionally, $CaCO_3$ has been produced by using concrete sludge generated in a ready-mixed concrete plant or the like, waste seawater obtained after producing magnesium hydroxide from seawater, or the like as a CaO-containing material, and supplying CO_2, and has been used to produce concrete.

[0043]

However, there has been a problem of requiring a dedicated facility for fixing CO_2 in a specific plant such as a ready-mixed concrete plant or a magnesium production plant.

[0044]

In production of concrete, a mineral admixture referred to as the word "tancal", which contains $CaCO_3$ as a main component, is used. An example of tancal used in a mineral admixture for concrete is CALFINDER manufactured by Omi Mining Co., Ltd. (https://www.omi-mining.co.jp/business/calcium-carbonate/Calfinder/), which has a $CaCO_3$ content of 90% by mass or more. Calculation of a Ca content in this 90% by mass of $CaCO_3$ provides 36% by mass of the Ca content. This type of $CaCO_3$ is described as calcium carbonate produced by pulverizing limestone ($CaCO_3$), and is so-called "heavy calcium carbonate"; heavy calcium carbonate means calcium carbonate produced by pulverizing limestone ($CaCO_3$), and thus is produced through a process including no reaction step with CO_2, therefore providing no effect of fixing atmospheric CO_2.

[0045]

Examples of materials used in a mineral admixture for concrete include Ecotancal® manufactured by Nippon Concrete Industries Co., Ltd. (https://www.ncic.co.jp/products/environment/ecoCaco3.html), which has a $CaCO_3$ purity of 97 to 99% and high whiteness. This type of $CaCO_3$ is calcium carbonate referred to as so-called "light calcium carbonate", which is also referred to as "precipitated calcium carbonate". This type of $CaCO_3$ is produced by a reaction with CO_2. The light calcium carbonate (precipitated calcium carbonate) has a $CaCO_3$ content of 95% by mass or more and a Ca content of 38% by mass or more.

[0046]

Reference 2 (Sato, Haruki and Kosone, Kazuyoshi, "Discrimination between Natural Calcium Carbonate and Synthetic Calcium Carbonate", Reports of the Central Custom Laboratory, 59, p.101-112) discloses an analysis of various

commercially-available calcium carbonate products by fluorescent X-ray and describes 97% by mass or more as a value of "C, O, and Ca". Accordingly, a calcium carbonate product having a $CaCO_3$ content of less than 90% by mass, i.e., a material having a Ca content of less than 36% by mass, has not yet been used as a mineral admixture to produce concrete. In addition, conventional concrete mineral admixtures have employed only materials with high whiteness. Particularly, a calcium carbonate product produced by a reaction with CO_2 (light calcium carbonate (precipitated calcium carbonate)) has a $CaCO_3$ content of 95% by mass or more and a Ca content of 38% by mass or more.

[0047]

Tancal, which is used as a commercially-available mineral admixture for concrete, has a sieve permeability of 100% for passing a sieve with an opening size of 600 μm, a sieve permeability of 90% or more for passing a sieve with an opening size of 150 μm, and a sieve permeability of 70% or more for passing a sieve with an opening size of 75 μm.

[0048]

Calcined dust has a Ca content of about 30% by mass, which represents 66% by mass or less or 57% by mass or less, and only generates a substance having a Ca content of less than 38% by mass or less than 36% by mass even when hydrated and carbonated according to formula (2) and formula (3). Note that hydration and carbonation of calcined dust, which has a Ca content of about 30% by mass as described above, according to formula (2) and formula (3) generates a substance having a Ca content of about 22% by mass. Furthermore, calcined dust is presumed not to appear white. For these reasons, calcined dust has not been used for concrete production.

[0049]

The inventors of the present invention investigated a raw material for producing a mineral admixture that contains $CaCO_3$ as a main component without the use of a dedicated facility for fixing CO_2 in a specific plant; revealed that the result of producing concrete using a material produced from calcined dust, which is usually discarded, and measuring the compressive strengths (N/mm^2) at material ages of 7 days and 28 days were comparable with or exceeded the result obtained using a commercially-available tancal and the result obtained using fine-powdery blast-furnace slag; and found that a material produced from calcined dust can be utilized as a mineral admixture. The present invention was made by these findings.

[0050]

The measurement described above was performed by a method in accordance with JIS A 1108: 2018. A composition obtained using only normal Portland cement as a cementitious binder was designated as Normal composition, with the mass ratio of water/bond material (W/B) being set to 50%. A composition obtained using high-early-strength Portland cement and blast-furnace slag was designated as Slag composition, with the mass ratio of high-early-strength Portland cement to blast-furnace slag being set to 1:9 and the W/B being set to 47%. A composition obtained using commercially-available tancal was designated as Tancal composition, with high-early-strength Portland cement, blast-furnace slag, and water being used in the same amounts as in Slag composition, the mass ratio of high-early-strength Portland cement and blast-furnace slag to tancal being set to 3:2, and the W/B being set to 47%. A composition obtained using a material produced from calcined dust is designated as Calcined dust-produced material composition, with a material produced from calcined dust being used instead of Tancal in Tancal composition, the mass ratio of the same high-early-strength Portland cement and blast-furnace slag to the material produced from calcined dust being set to 3:2, and the W/B being set to 47%. It should be noted that the material produced from calcined dust is a material that is generated by reacting calcined dust with water and fixing CO_2 by adsorption, absorption, or reaction as described below and contains $CaCO_3$ as a main component.

[0051]

In the measurement, a sample casted in a framework was detached the next day, and subjected to standard curing (underwater curing at 20°C). The measurement results showed that Normal composition had a compressive strength of 39 N/mm^2 at a material age of 7 days and a compressive strength of 51 N/mm^2 at a material age of 28 days; that Slag composition had a compressive strength of 21 N/mm^2 at a material age of 7 days and a compressive strength of 26 N/mm^2 at a material age of 28 days; and that Tancal composition had a compressive strength of 42 N/mm^2 at a material age of 7 days and a compressive strength of 56 N/mm^2 at a material age of 28 days. By contrast, Calcined dust-produced material composition had a compressive strength of 53 N/mm^2 at a material age of 7 days and a compressive strength of 64 N/mm^2 at a material age of 28 days, and provided compressive strengths exceeding those of Normal composition, Slag composition, and Tancal composition. This revealed that a material produced from calcined dust can be sufficiently utilized as a mineral admixture for concrete.

[0052]

Calcined dust is a by-product obtained from a step of calcining limestone, and represents waste Ca components containing CaO, and thus can be reacted with water according to formula (2) to generate slaked lime ($Ca(OH)_2$). Subsequently, according to formula (3), CO_2 can be adsorbed, absorbed, reacted, and fixed chemically to produce a mineral admixture for concrete (main component: $CaCO_3$).

[0053]

The mineral admixture thus generated can be utilized for production of concrete, thereby fixing and reserving CO_2 from the atmosphere, exhaust gas, or the like. It should be noted that since limestone contains $CaCO_3$ as a main component, the use of limestone as a mineral admixture does not represent fixation and reservation of CO_2, but the use of calcined dust can provide fixation and reservation of CO_2.

[0054]

Calcined dust, which is a by-product obtained from a step of calcining limestone, contains CaO, and production of $CaCO_3$, which is a main component of a mineral admixture for concrete, from CaO can employ a known hydration step and a known carbonation step.

[0055]

For example, dry processes can be used as methods for hydration and carbonation. Reference 3 (Itatani, Kiyoshi and seven colleagues, "Preparation of Granular-Hydrated Lime by Reaction of Quicklime with Water", Gypsum & Lime No.234, p.306-314 (1991)) describes a method of producing $Ca(OH)_2$ in a dry system by spraying deionized water from the top onto powdered CaO with a spray, stirring them with a scrubber, causing hydration reaction of CaO. In addition, Reference 4 ("Slaking of Limestone", the Society of Inorganic Materials, Japan, Gypsum and Lime, 1957, vol. 29, p.1434-1335 (1957)) describes that most of small and medium-sized business have employed a method of depositing CaO on a floor or container and pouring water to cause hydration. Reference 4 also describes that an Anker's automatic hydrator, a Schnlthess's automatic hydrator, or the like can be employed as a drying mechanical means that performs hydration by adding water to CaO, and that a method of conducting hydration and carbonation reactions by natural weathering can also be employed because CaO spontaneously undergoes hydration action even when contacting with moisture in the air, and thus spontaneously absorbs moisture in the air and generates $Ca(OH)_2$, and in turn, $Ca(OH)_2$ absorbs CO_2 in the air and generates $CaCO_3$. Furthermore, Reference 5 (Yasue, Tamotsu and two colleagues, "Research Trend of Lime", Inorganic Materials, Vol.1, No.252,

p.370-381 (1994)) also describes that several researches are directed to carbonation. In this way, dry techniques have been widely used as methods for hydration and carbonation, and production of $CaCO_3$, which is a main component of a mineral admixture for concrete, from CaO can employ a known hydration step and a known carbonation step.

[0056]

As methods for hydration and carbonation, wet methods may also be used in addition to dry methods. Fig. 3 depicts an example of known wet hydration steps and carbonation steps. In the hydration/carbonation steps shown in Fig. 3, a known production apparatus for subjecting CaO to hydration and carbonation to produce $CaCO_3$. Since calcined dust contains CaO, an apparatus and method can be used similar to a conventionally known apparatus and method of subjecting CaO to hydration and carbonation to produce $CaCO_3$.

[0057]

A $CaCO_3$-producing apparatus 10 contains a slaker tank 11, a dissolution tank 12, a filter 13, a reaction tank 14, a maturation tank 15, a washer 16, a dehydrator/drier 17, and a filler 18. To the slaker tank 11, water and calcined dust, which represents waste Ca components containing CaO, are charged. In the slaker tank 11, CaO in calcined dust reacts with water and generated $Ca(OH)_2$ according to formula (2).

[0058]

The reaction tank 14 receives CO_2 supplied, performs a reaction with CO_2 according to formula (3), and generates $CaCO_3$.

[0059]

The dehydrator/drier 17 dehydrates and dries $CaCO_3$. The filler 18 packs dried $CaCO_3$. The packed $CaCO_3$ is shipped as a product.

[0060]

A mineral admixture containing $CaCO_3$ as a main component and produced by hydration and carbonation using calcined dust as a raw material has a Ca content of 37% by mass or less or 35% by mass or less, unlike commercially-available tancal, which has a Ca content of 36% by mass or more, particularly unlike commercially-available light calcium carbonate (precipitated calcium carbonate), which has a Ca content of 38% by mass or more. The mineral admixture contains Ca by virtue of the presence of $CaCO_3$, with the Ca content being preferably 5% by mass or more.

[0061]

Accordingly, the mineral admixture for concrete is produced by reacting a

by-product obtained in a step of producing CaO with water and CO_2, and contains 37% by mass or less of Ca. The preferred lower limit value of the Ca content of the mineral admixture for concrete is 5% by mass as described above, and is more preferably 10% by mass, even more preferably 15% by mass. The lower limit value is preferably 17% by mass rather than 15% by mass, even more preferably 20% by mass. The upper limit value of the Ca content of the mineral admixture for concrete is 37% by mass as described above, and may be 36% by mass or less, 35% by mass or less, 34% by mass or less, 33% by mass or less, 32% by mass or less, 30% by mass or less, 28% by mass or less, or 25% by mass or less.

[0062]

The by-product is not limited to these, and calcined dust obtained in a step of calcining limestone in a step of producing CaO can be used. In the by-product, the Ca content is 66% by mass or less, and may be 57% by mass or less

[0063]

The mineral admixture for concrete can be produced in the same manner as conventional methods. Fig. 4 illustrates a production flow of a mineral admixture for concrete. The following description is provided as using known dry methods for hydration and carbonation. In production of the mineral admixture for concrete, a by-product obtained in a step of producing CaO is provided as a raw material, and water is sprayed onto the raw material to cause a reaction at step 200. Subsequently, at step 201, the product generated by reacting the raw material and water is charged in a cylindrical tube rotating, then undergoes aeration, and thereby is reacted with CO_2 in the air. This reaction generates $CaCO_3$, and a material containing the generated $CaCO_3$ as a main component is used as a mineral admixture. Accordingly, the reaction with water can occur even not in the form of a solution, and the reaction with CO_2 after the reaction with water can also occur even not in the form of a solution. Similarly, a step of reacting water with a material containing a by-product obtained in a step of producing CaO can occur even not in the form of a solution, and a reaction with CO_2 after the reaction with water can also occur even not in the form of a solution. Additionally, a step of reacting water with a material containing a by-product obtained in a step of producing CaO may be a reaction in a solution, and the reaction with CO_2 after the reaction with water may be a reaction in a solution.

[0064]

The mineral admixture produced in this manner was subjected to sieving test to measure the percentage passing by mass. Particle size determination

employed a stainless-steel sieve with a frame diameter of 200 mm manufactured by Nonakarikaki Co., Ltd. in accordance with JIS Z 8801-1. The relationship between the opening size and the percentage passing by mass (%) of a sieve is as follows: 75 μm: 62.0%, 106 μm: 68.4%, 250 μm: 87.3%, 425 μm: 96.4%, 850 μm: 99.8%, 2 mm: 99.9%, and 4.75 mm: 100%.

[0065]

From the percentage passing by mass (%), a grain size accumulation curve was created by plotting a percentage passing by mass (%) on an ordinate axis and particle diameter on a logarithmic abscissa axis. The grain size accumulation curve thus created is shown in Fig. 5. The values of percentage passing by mass (%) at a particle diameter of 600 μm, 150 μm, and 75 μm were read from the grain size accumulation curve shown in Fig. 5, resulting in a value of 99% for the percentage passing by mass at a particle diameter of 600 μm, a value of 76% for the percentage passing by mass at a particle diameter of 150 μm, and a value of 62% for the percentage passing by mass at a particle diameter of 75 μm.

[0066]

As derived in this manner, the value of the percentage passing by mass at a particle diameter of 600 μm is 70% or more, the value of the percentage passing by mass at a particle diameter of 150 μm is 45% or more, and the value of the percentage passing by mass at a particle diameter 75 μm is 30% or more. Additionally, the value of the percentage passing by mass of the mineral admixture at a particle diameter of 600 μm obtained in this manner is preferably 75% or more, more preferably 80% or more, even more preferably 85% or more. The value of the percentage passing by mass at a particle diameter of 600 μm is preferably 90% or more rather than 85% or more, more preferably 95% or more, even more preferably 97% or more.

[0067]

The value of the percentage passing by mass of the mineral admixture at a particle diameter of 150 μm obtained in this manner is 50% or more, preferably 55% or more, more preferably 60% or more, even more preferably 65% or more. The value of the percentage passing by mass at a particle diameter of 150 μm is 70% or more rather than 65% or more, more preferably 75% or more. Additionally, the upper limit value of the value of the percentage passing by mass at a particle diameter of 150 μm can be 95%, or 90%, or 85%.

[0068]

The value of the percentage passing by mass of the mineral admixture at a

particle diameter of 75 μm obtained in this manner is preferably 35% or more, more preferably 40% or more, even more preferably 45% or more. The value of the percentage passing by mass at a particle diameter of 75 μm is preferably 50% or more rather than 45% or more, more preferably 55% or more. Additionally, the upper limit value of the value of the percentage passing by mass at a particle diameter of 75 μm can be 95%, or 90%, or 85%, or 80%, or 75% or 70%.

[0069]

Furthermore, a portion of the mineral admixture produced as described above was analyzed with an energy dispersive fluorescent X-ray analyzer manufactured by Rigaku Corporation (model: EDXL300, measurement condition: FP (fundamental parameter) method), and revealed to have a Ca content of 33% by mass. Even if the mineral admixture has a Ca content of 35% by mass, the Ca content of calcined dust, a raw material, is 56.9% by mass, which is 57% by mass or less. Furthermore, even if the mineral admixture has a Ca content of 37% by mass, the Ca content of calcined dust, a raw material, is nearly 60% by mass (about 62% by mass), which is 66% by mass or less.

[0070]

The mineral admixture, which was produced through hydration and carbonation, displayed gray color as with the calcined dust in Fig. 2 (b). The mineral admixture thus produced displays brown, gray, black, or another color rather than white. This color is one of colors defined in Appendix Table in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colours), such as sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black. Additionally, in JIS Z 8102: 2001, the common colors listed above are permitted to be designated with modifier names using the terms defined in Table 3 in Definition 7.2 and Table 4 in Definition 7.3, and any of names of the common color listed above also includes a color modified by “light”, “strong”, “deep”, “pale”, “soft”, “dull”, “dark”, “very pale”, “light grayish”, “grayish”, “dark grayish”, “very dark”, “medium”, defined in Table 3 in Definition 7.2 and Table 4 in Definition 7.3 in JIS Z 8102: 2001 (Definition 11.2, Table 3 in Definition 7.2 and Table 4 in Definition 7.3 in JIS Z 8102: 2001). The mineral admixture is a material having the particle diameter described above, or a material having the color described above, or a material having both.

[0071]

Moreover, the value derived by measuring the mineral admixture (calcium-containing material), which is produced by hydration and carbonation, in terms of whiteness W ($L^*a^*b^*$) in the Lab color space defined by International Commission on Illumination (CIE) may be less than 95, 90 or less, 85 or less, 80 or less, 75 or less, 70 or less, 65 or less, 60 or less, 55 or less, 50 or less, 45 or less, or 40 or less. Furthermore, the value derived by measuring the mineral admixture (calcium-containing material), which is produced by hydration and carbonation, in terms of a lightness L^* in the Lab color space defined by CIE may be less than 95, 90 or less, 85 or less, 80 or less, 75 or less, 70 or less, 65 or less, 60 or less, 55 or less, 50 or less, 45 or less, or 40 or less.

[0072]

A relationship between whiteness W ($L^*a^*b^*$) in the Lab color space defined by CIE and measured values L^*, a^*, and b^* is as shown in the formula (4) as below. L^* is a lightness in the Lab color space, and a^* and b^* are chromatic coordinates in the Lab color space.

$$W(L^*a^*b^*) = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2} \quad (4)$$

[0073]

A by-product generated in a calcining step for producing quicklime (CaO) is derived from dust or the like as a raw material, and thus tends to have a lower value of whiteness W ($L^*a^*b^*$) in the Lab color space defined by CLE as compared to common light calcium carbonate (precipitated calcium carbonate), and similarly, also tends to have a low value of lightness L^* in the Lab color space defined by CLE.

[0074]

Similar to the foregoing description, portions of the mineral admixture (calcium-containing material) produced through hydration and carbonation were measured as mineral admixture A and mineral admixture B, particularly with the following measuring device and measuring conditions. The measurement results are shown in Table 1.

Measuring device: spectrophotometric colorimeter SE7700, manufactured by Nippon Denshoku Industries Co., Ltd.

Measuring conditions: reflection, light source/visual field = C/2, filled and measured in a round cell with φ58 mm

[0075]

[Table 1]

	L*	a*	b*	W(L*a*b*)
MINERAL ADMIXTURE A	36.03	0.07	2.15	36
MINERAL ADMIXTURE B	35.90	0.17	2.54	36

[0076]

The results in Table 1 described above shows that mineral admixtures A and B exhibited low whiteness values W ($L^*a^*b^*$) of 36, and that mineral admixtures A and B also exhibited low lightness values L^* of 36.03 and 35.90, respectively.

[0077]

The mineral admixture is a calcium-containing material by virtue of the presence of $CaCO_3$, and the production flow shown in Fig. 4 is a production flow of a mineral admixture for concrete as well as one of production flows of a calcium-containing material.

[0078]

Fig. 6 illustrates a production flow of concrete. At step 300, a by-product obtained in a step of producing CaO is reacted with water and CO_2, thereby producing a mineral admixture containing 35% by mass or less of Ca. In particular, the mineral admixture is produced by the production step shown in Fig. 4.

[0079]

After the mineral admixture is produced, Portland cement, aggregate, water, and the mineral admixture are measured to provide a predetermined ratio at step 301. The Portland cement to be used can be high-early-strength Portland cement, but may be ordinary Portland cement. The aggregate includes fine aggregate and coarse aggregate. Fine aggregate is aggregate in which all particles have a size of 10 mm or less, with 85% by mass or more thereof having a size of 5 mm or less. By contrast, coarse aggregate is aggregate in which 85% by mass or more of all particles has a size of 5 mm or more. The volume ratio (s/a) of fine aggregate content to the total aggregate content in concrete can be within the range of, e.g., 35 to 55% in percentage. The mass ratio of water to Portland cement can be, e.g., 100:5 to 100:25. The mass of the mineral admixture can be within the range of 5 to 10 times the mass of the Portland cement.

[0080]

At step 302, the measured Portland cement, aggregate, water, and mineral admixture are charged in a concrete mixer. Subsequently, at step 303, the mixture

is kneaded with a stirring blade in the concrete mixer, thereby producing fresh concrete (ready-mixed concrete), which is uncured concrete.

[0081]

The ready-mixed concrete thus produced is conveyed to a construction site by a vehicle that conveys ready-mixed concrete, such as a concrete mixer vehicle, and is casted into a framework at the construction site. The casted concrete is cured for a predetermined period of time, followed by removal of the framework, thereby constructing a concrete structure.

[0082]

In production of concrete, a chemical admixture such as a water-reducing agent can be used in addition to Portland cement, aggregate, water, and a mineral admixture derived from a by-product generated in a production process of CaO, and at least one of fine-powdery blast-furnace slag, fly ash, silica fume, an expanding material, or a waterproofing material can also be mixed and used in addition to the mineral admixture derived from the by-product, and Portland cement.

[0083]

As described so far, since a by-product obtained in a step of calcining limestone is used, CO_2 is not generated by production. The mineral admixture is produced only by reacting the by-product with CO_2, and thus represents a negative material. The mineral admixture can also be provided at a low price because of the use of the by-product.

[0084]

The by-product is a material containing solid Ca and can provide fixation of CO_2 at any place, thus eliminating need for an extensive dedicated facility in production of a mineral admixture. Moreover, a Ca-containing material produced by the production method as described above is a material containing $CaCO_3$, and thus can be used as a fertilizer, a soil conditioner, a plant growth substance, or an agricultural material for cultivating plants, in the same manner as $CaCO_3$ (tancal) commonly, widely marketed as fertilizers, soil conditioners, and the like, and furthermore can be used as a raw material for producing the same.

[0085]

A mineral admixture, a method of producing a mineral admixture, concrete, and a method of producing concrete, and a method of producing a calcium-containing material according to the present invention have been described in detail so far with reference to the embodiments depicted in the drawings, but the present invention is not limited to the aforementioned embodiments, and can be changed within the

range that can be contemplated by one ordinary skilled in the art, with another embodiment, addition, modification, deletion, or the like. Any of embodiments is encompassed within the range of the present invention as long as it provides action or an effect of the present invention.

Reference Signs List

[0086]

10: production apparatus

11: slaker tank

12: dissolution tank

13: filter

14: reaction tank

15: maturation tank

16: washer

17: dehydrator/drier

18: filler

CLAIMS

1. A mineral admixture for concrete, the mineral admixture being produced by reacting a by-product obtained in a step of producing quicklime with water and carbon dioxide, and comprising 5% by mass or more and 37% by mass or less of calcium.

2. The mineral admixture for concrete according to claim 1, wherein the by-product is calcined dust obtained in a step of calcining limestone in a step of producing the quicklime.

3. The mineral admixture for concrete according to claim 2, the mineral admixture being produced by reacting the calcined dust with the water and then with the carbon dioxide.

4. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

5. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the by-product is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colours), and derivatives thereof designated with the modifier term ”light”, “strong”, “deep”, “pale”, “soft”, “dull”, “dark”, “very pale”, “light grayish”, “grayish”, “dark grayish”, “very dark”, or “medium”.

6. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or

more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering, and is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

7. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the mineral admixture is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

8. A method of producing a mineral admixture for concrete, the mineral admixture comprising 5% by mass or more and 37% by mass or less of calcium, and the method comprising a first step of providing, as a raw material, a by-product obtained in a step of producing quicklime, and reacting the raw material with water, and a second step of reacting a product thus obtained by the first step with carbon dioxide.

9. The method of producing a mineral admixture for concrete according to claim 8, wherein the by-product is calcined dust obtained in a step of calcining limestone in the step of producing quicklime.

10. The method of producing a mineral admixture for concrete according to claim 8 or 9, wherein the by-product has a cumulative fraction value of 70% or more

for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

11. The method of producing a mineral admixture for concrete according to claim 8 or 9, wherein the by-product is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

12. The method of producing a mineral admixture for concrete according to claim 8 or 9, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering, and is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

13. A concrete comprising a mineral admixture comprising 5% by mass or more and 37% by mass or less of calcium,

wherein the mineral admixture is produced by reacting a by-product obtained in a step of producing quicklime with water and carbon dioxide.

14. The concrete according to claim 13, wherein the by-product is calcined dust obtained in a step of calcining limestone in a step of producing the quicklime.

15. The concrete according to claim 14, wherein the concrete is produced by reacting the water with the calcined dust and then with the carbon dioxide.

16. The concrete according to any one of claims 13 to 15, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

17. The concrete according to any one of claims 13 to 15, wherein the by-product is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term ”light”, “strong”, “deep”, “pale”, “soft”, “dull”, “dark”, “very pale”, “light grayish”, “grayish”, “dark grayish”, “very dark”, or “medium”.

18. The concrete according to any one of claims 13 to 15, wherein 400 kg or less of the mineral admixture is contained in 1 m^3 of the concrete.

19. The concrete according to any one of claims 13 to 15, wherein the concrete comprises Portland cement, aggregate, water, and the mineral admixture,

wherein the mineral admixture has a mass within the range of five to ten times the mass of the Portland cement.

20. A method of producing concrete, comprising:

producing a mineral admixture comprising 5% by mass or more and 37% by mass or less of calcium, by reacting a by-product obtained in a step of producing quicklime with water and carbon dioxide, and

producing the concrete by kneading the mineral admixture thus produced,

aggregate, and water.

21. The method of producing concrete according to claim 20, wherein the by-product is calcined dust obtained in a step of calcining limestone in a step of producing the quicklime.

22. The method of producing concrete according to claim 20 or 21, wherein the producing the mineral admixture comprises a first step of reacting the water with the by-product, and a second step of reacting a product thus obtained by the first step with carbon dioxide.

23. The method of producing concrete according to claim 20 or 21, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

24. The method of producing concrete according to claim 20 or 21, wherein 400 kg or less of the mineral admixture is contained in 1 m^3 of the concrete.

25. The method of producing concrete according to claim 20 or 21, the concrete comprises Portland cement, aggregate, water, and a mineral admixture,

wherein the mineral admixture has a mass within the range of five to ten times the mass of the Portland cement.

26. A method of producing a calcium-containing material, the method comprising a first step of providing, as a raw material, a by-product obtained in a step of producing quicklime, and reacting a material comprising the raw material with water, and a second step of reacting a product thus obtained by the first step with carbon dioxide.

27. A method of producing a calcium-containing material, the calcium-containing material having a calcium content of 37% by mass or less, and the method comprising a first step of providing, as a raw material, a by-product obtained in a step of producing quicklime, and reacting a material comprising the raw material

with water, and a second step of reacting a product thus obtained by the first step with carbon dioxide.

28. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

29. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colours), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

30. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering, and is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with the modifier term "light", "strong", "deep", "pale", "soft", "dull", "dark", "very pale", "light grayish", "grayish", "dark grayish", "very dark", or "medium".

31. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a calcium content of 66% by mass or less.

32. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a calcium content of 66% by mass or less, and

wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering.

33. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a calcium content of 66% by mass or less, and

wherein the by-product is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (“Names of non-luminous object colors”), and derivatives thereof designated with the modifier term ”light”, “strong”, “deep”, “pale”, “soft”, “dull”, “dark”, “very pale”, “light grayish”, “grayish”, “dark grayish”, “very dark”, or “medium”.

34. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product has a calcium content of 66% by mass or less, and

wherein the by-product has a cumulative fraction value of 70% or more for particles having a particle diameter of 600 μm or less, a cumulative fraction value of 50% or more for particles having a particle diameter of 150 μm or less, and a cumulative fraction value of 30% or more for particles having a particle diameter of 75 μm or less, on a volume basis as measured by laser diffraction/scattering, and is powder having any colors of sand, Gofun white, ecru, ivory white, silver dark gray, brownish dark gray, dark gray, greyish dark green, lead, gray, soot-colored bamboo, dark brown, ink black, black, iron black, silver, ivory, sky gray, pearl gray, silver gray, ash gray, rose gray, gray, steel gray, straight gray, charcoal gray, lamp black, and black defined in Appendix Table 1 in Japanese Industrial Standards (JIS) Z 8102: 2001 (Names of non-luminous object colors), and derivatives thereof designated with

the modifier term ”light”, “strong”, “deep”, “pale”, “soft”, “dull”, “dark”, “very pale”, “light grayish”, “grayish”, “dark grayish”, “very dark”, or “medium”.

35. The method of producing a calcium-containing material according to claim 26 or 27, wherein the by-product is calcined dust obtained in a step of calcining limestone in a step of producing the quicklime.

36. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the mineral admixture is powder having a whiteness value of less than 95, the whiteness value denoting whiteness W ($L^*a^*b^*$) in the Lab color space defined by International Commission on Illumination (CIE).

37. The mineral admixture for concrete according to any one of claims 1 to 3, wherein the mineral admixture is powder having a lightness value of less than 95, the lightness value denoting a lightness L^* in the Lab color space defined by International Commission on Illumination (CIE).

38. The method of producing a calcium-containing material according to claim 26 or 27, wherein the calcium-containing material is powder having a whiteness value of less than 95, the whiteness value denoting whiteness W ($L^*a^*b^*$) in the Lab color space defined by International Commission on Illumination (CIE).

39. The method of producing a calcium-containing material according to claim 26 or 27, wherein the calcium-containing material is powder having a lightness value of less than 95, the lightness value denoting a lightness L^* in the Lab color space defined by International Commission on Illumination (CIE).