

[DESCRIPTION]

[Title of Invention]

CEMENT COMPOSITION FOR GROUND IMPROVEMENT, CONSTRUCTION METHOD
FOR GROUND IMPROVEMENT, AND GROUND IMPROVEMENT BODY

[Technical Field]

[0001] The present invention relates to a cement composition for ground improvement, which exhibits high workability and strength development properties even in warm climates and regions; and a construction method for ground improvement and a ground improvement body that use the cement composition. Moreover, the term "warm" in this Description means an annual average temperature of 25°C or higher.

[Background Art]

[0002] Cement-based ground improvement materials are often used for improving foundation ground of structures, constructing temporary ground, preventing liquefaction, improving construction-displaced soil and construction sludge, solidifying contaminated soil and the like. Depending on the type of soil to be treated, the purpose of improvement and the like, these cement-based ground improvement materials can impart a variety of functions through addition of a variety of auxiliary materials to Portland cement that is used as a primary material.

In recent years, ground improvement materials that use large amounts of by-products emitted by the iron and steel industry and the power industry have been developed in order

to effectively use industrial waste. For example, PTL 1 and 2 disclose coal ash capable of improving homogeneity during improvement (mixing) by using a cement composition, which contains cement and coal ash having a specific brightness obtained by pulverizing coal ash having a high unburned carbon content, to improve cohesive soil ground; methods for producing the coal ash; and cement compositions.

[Citation List]

[Patent Literature]

[0003] [PTL 1] Japanese Patent Application Publication No. 2018-122260

[PTL 2] Japanese Patent Application Publication No. 2018-122290

[Summary of Invention]

[Technical Problem]

[0004] When ground improvement is carried out in warm climates and regions, the fluidity retention time of a mixture of a ground improvement material and water (hereinafter referred to as a "ground improvement material slurry") is short, as the result, if ground improvement work is delayed, the viscosity of the ground improvement material slurry becomes too high and the work may not be possible. In such a case, the ground improvement material slurry must be discarded, but this causes a further delay in the work and causes problems in terms of facilitating effective use of waste materials.

If the fluidity retention time of the ground improvement material slurry can be extended, workability is improved, loss of resources in ground improvement work can be reduced, and it is possible to facilitate effective use of waste materials (by-products) such as coal ash.

Therefore, an object of the present invention is to provide a cement composition for ground improvement and the like, which can further extend the fluidity retention time of a ground improvement material slurry even in warm climates and regions and which exhibits high strength development properties.

[Solution to Problem]

[0005] As a result of diligent research into cement compositions for ground improvement able to achieve the object mentioned above, the inventors of the present invention found that the object mentioned above could be achieved by a cement composition for ground improvement, which contains fly ash that satisfies specific conditions, and thereby completed the present invention.

That is, the present invention is a cement composition for ground improvement and the like, which has the following features.

[0006] [1] A cement composition for ground improvement, which contains at least fly ash that satisfies all of conditions (F1) to (F5) below and Portland cement, wherein a

content of the fly ash is 10 to 40 mass% when a total amount of the fly ash and the Portland cement is 100 mass%:

(F1) a Blaine specific surface area of the fly ash is 2500 to 6000 cm^2/g ;

(F2) a mass reduction rate of the fly ash is 5 mass% or less after the fly ash is heated for 15 minutes at a temperature of $975 \pm 25^\circ\text{C}$;

(F3) a content of SiO_2 in the fly ash is 50 mass% or more;

(F4) in the fly ash, a sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed is 2800 to 11,000 cm^2/cm^3 ; and

(F5) in the fly ash, a sphere equivalent specific surface area of amorphous particles containing Ca (calcium) is 2100 to 22,500 cm^2/cm^3 .

[2] The cement composition for ground improvement according to [1] above, wherein the fly ash also satisfies condition (F6) below:

(F6) in the fly ash, a sphere equivalent specific surface area of particles in which mullite and an amorphous substance are mixed is 1900 to 9500 cm^2/cm^3 .

[3] The cement composition for ground improvement according to [1] or [2] above, wherein the fly ash also satisfies condition (F7) below:

(F7) in the fly ash, a sphere equivalent specific surface area of amorphous particles not containing Ca is 2100 to 9000 cm^2/cm^3 .

[4] The cement composition for ground improvement according to any one of [1] to [3] above, which further contains one or more types of gypsum selected from among anhydrous gypsum, gypsum hemihydrate and gypsum dihydrate, wherein

a content of the gypsum is 6.0 mass% or less in terms of SO_3 when a total amount of Portland cement, fly ash and the gypsum is 100 mass%.

[5] A construction method for ground improvement, wherein ground is improved by mixing soil with a ground improvement material slurry that contains at least water and the cement composition for ground improvement according to any one of [1] to [4] above.

[6] A ground improvement body obtained by mixing the ground improvement material slurry according to [5] above with cohesive soil that satisfies all of conditions (S1) to (S3) below:

(S1) a moisture content is 70 to 150%;

(S2) an allophane content, as measured using an acidic oxalate extraction method, is 5.0% or more; and

(S3) when cohesive soil is mixed with a slurry containing 150 mg of $\text{Ca}(\text{OH})_2$ and 100 ml of water, an amount of

Ca(OH)₂ adsorbed by the cohesive soil is 80 mg or more per 1 g of the cohesive soil

[Advantageous Effects of Invention]

[0007] The cement composition for ground improvement of the present invention can extend the fluidity retention time of a ground improvement material slurry even in warm climates and regions and exhibits high strength development properties. In addition, according to the construction method for ground improvement of the present invention, it is possible to improve workability, reduce loss of resources and facilitate effective use of waste materials. Furthermore, the ground improvement body of the present invention exhibits high strength.

[Description of Embodiments]

[0008] As mentioned above, the present invention is a cement composition for ground improvement, a construction method for ground improvement, and a ground improvement body.

First, an explanation will be given of the cement composition for ground improvement of the present invention.

1. Cement composition for ground improvement

This cement composition contains at least fly ash that satisfies the specific conditions mentioned above and Portland cement, wherein the content of the fly ash is 10 to 40 mass% if the total amount of the fly ash and the Portland cement is taken to be 100 mass%. The workability of the ground improvement material slurry deteriorates if the content of the

fly ash is less than 10 mass%, and the strength development properties of the cement composition for ground improvement deteriorate if the content of the fly ash exceeds 40 mass%. Moreover, the content of the fly ash is preferably 12 to 35 mass%, and more preferably 14 to 30 mass%.

[0009] (i) Portland cement

The Portland cement used in the present invention can be one or more types selected from among ordinary Portland cement, high-early-strength Portland cement, moderate heat Portland cement and low heat Portland cement, as specified in Japan Industrial Standard (JIS) R 5210 "Portland Cement".

Of these, the Portland cement is preferably ordinary Portland cement and/or high-early-strength Portland cement in order to improve the strength development properties of the cement composition for ground improvement.

[0010] (ii) Fly ash

The fly ash used in the present invention satisfies all of conditions (F1) to (F5) below.

(F1) The Blaine specific surface area of the fly ash is 2500 to 6000 cm²/g

(F2) The mass reduction rate of the fly ash is 5 mass% or less after the fly ash is heated for 15 minutes at a temperature of 975 ± 25°C

(F3) The content of SiO₂ in the fly ash is 50 mass% or more

(F4) In the fly ash, the sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed is 2800 to 11,000 cm^2/cm^3

(F5) In the fly ash, the sphere equivalent specific surface area of amorphous particles containing Ca is 2100 to 22,500 cm^2/cm^3

[0011] Detailed explanations will now be given of fly ash conditions (F1) to (F5) above.

(F1): If the Blaine specific surface area of the fly ash is less than 2500 cm^2/g , the strength development properties of the cement composition for ground improvement deteriorate, and if the Blaine specific surface area of the fly ash exceeds 6000 cm^2/g , the viscosity of the ground improvement material slurry increases, and it is also difficult to procure fly ash having a Blaine specific surface area of more than 6000 cm^2/g . Moreover, the Blaine specific surface area is preferably 2700 to 5000 cm^2/g , and more preferably 2900 to 4000 cm^2/g .

[0012] (F2): If the mass reduction rate of the fly ash exceeds 5 mass% after the fly ash is heated for 15 minutes at a temperature of $975 \pm 25^\circ\text{C}$, the strength development properties of the cement composition for ground improvement deteriorate. Moreover, this mass reduction rate is preferably 4.3 mass% or less, and more preferably 3.5 mass% or less, from the perspectives of ease of procurement and strength development properties.

[0013] (F3): If the content of SiO_2 in the fly ash is less than 50 mass%, the strength development properties of the cement composition for ground improvement deteriorate.

Moreover, the content of SiO_2 is preferably 52 to 70 mass%, and more preferably 54 to 65 mass%, from the perspectives of ease of procurement and strength development properties.

[0014] (F4): In the fly ash, if the sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed falls outside the range 2800 to 11,000 cm^2/cm^3 , there are concerns that the workability of the ground improvement material slurry and the strength development properties of the cement composition for ground improvement will deteriorate. Moreover, the sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed is preferably 4000 to 10,000 cm^2/cm^3 , and more preferably 5000 to 9000 cm^2/cm^3 .

[0015] (F5): In the fly ash, if the sphere equivalent specific surface area of amorphous particles containing Ca falls outside the range 2100 to 22,500 cm^2/cm^3 , there are concerns that the workability of the ground improvement material slurry and the strength development properties of the cement composition for ground improvement will deteriorate. Moreover, the sphere equivalent specific surface area of the amorphous particles containing Ca is preferably 4000 to 20,000 cm^2/cm^3 , and more preferably 7000 to 18,500 cm^2/cm^3 .

[0016] In addition, in order to improve the workability, and especially fluidity, of the ground improvement material slurry and improve the strength development properties of the cement composition for ground improvement, the sphere equivalent specific surface area of particles in which mullite and an amorphous substance are mixed in the fly ash is preferably 1900 to 9500 cm²/cm³, more preferably 3000 to 9000 cm²/cm³, and further preferably 4500 to 9000 cm²/cm³. For the same reasons, the sphere equivalent specific surface area of amorphous particles not containing Ca in the fly ash is preferably 2100 to 9000 cm²/cm³, more preferably 3000 to 8500 cm²/cm³, and further preferably 4500 to 8500 cm²/cm³.

[0017] In addition, fly ash generally contains 5 to 25 mass% of quartz, and the lattice volume of quartz in the fly ash used in the present invention is a value determined using the Rietveld analysis method, and is preferably 113.5 to 114.5 Å³. If the lattice volume of the quartz falls within the range mentioned above, the fluidity of the ground improvement material slurry and the strength development properties of the cement composition for ground improvement are further improved. Moreover, the lattice volume of the quartz is more preferably 113.6 to 114.4 Å³, and further preferably 113.7 to 114.3 Å³.

Rietveld analysis of quartz in the fly ash can be carried out on the basis of X-Ray diffraction charts of fly ash using, for example, analytical software (Topas ver. 2.1)

produced by Bruker and 331161 (Quartz) as crystal structure data (ICDD number).

In addition, the sphere equivalent specific surface area of quartz particles in the fly ash is preferably 1100 to 12,500 cm^2/cm^3 , more preferably 2500 to 10,000 cm^2/cm^3 , and further preferably 4000 to 10,000 cm^2/cm^3 , in order to improve strength development properties and the like.

[0018] Fly ash particles are classified into five types, namely (i) particles in which iron oxide and an amorphous substance are mixed, (ii) particles in which mullite and an amorphous substance are mixed, (iii) amorphous particles not containing Ca, (iv) amorphous particles containing Ca, and (v) quartz particles, by means of steps (1) to (4) below.

(1) Sample preparation step

This step is a step in which a test piece is prepared by mixing fly ash and a resin and then curing. By dispersing the fly ash in the resin, fly ash particles do not overlap, and individual particles can be precisely extracted and measured in terms of property values in the particle analysis described later.

The resin should be one in which shrinkage is low during a curing step and which does not undergo cracking, and examples thereof include epoxy resins, acrylic resins, polyester resins and methacrylic resins. The mixing proportion of the resin is preferably 0.8 to 4 relative to the fly ash in terms of volume ratio. If the mixing proportion of

the resin falls within this range, multiple particles can be dispersed without coming into contact with each other, and it is possible to obtain cross sections of multiple particles by carrying out the polishing described below.

[0019] Next, an imaging surface of a cured test piece is polished. If unevenness occurs on the imaging surface or a cross section of a particle cannot be adequately obtained, it is not possible to accurately measure the particle diameter or shape of the particle, and precision in the particle analysis described later deteriorates.

The apparatus used for polishing the imaging surface of the test piece is not particularly limited, and a commonly used polishing apparatus can be used. In addition, the polishing material used in the polishing step is not particularly limited, and examples thereof include silicon carbide polishing materials, boron carbide polishing materials, diamond pastes and alumina powders. In addition, the polishing mentioned above is preferably buff polishing using an alumina powder or the like having a particle diameter of 0.3 to 3 μm as a polishing material, and is more preferably carried out using a cross section polisher using an argon ion beam in order to ensure that little unevenness occurs on the imaging surface.

[0020] Finally, a vapor deposited film is formed on the surface of the test piece whose imaging surface has been polished, thereby imparting the test piece with electrical

conductivity. In the particle analysis described later, the test piece is irradiated with an electron beam, but because the fly ash and the resin are not electrically conductive, if a backscattered electron image is obtained without forming a vapor deposited film on the test piece, the surface of the test piece becomes electrically charged and an accurate backscattered electron image cannot be obtained. Therefore, an electrically conductive vapor deposited film is formed on the surface of the test piece in order to obtain an accurate backscattered electron image.

The vapor deposited film is not particularly limited as long as this film can impart the surface of the test piece with electrical conductivity, and examples thereof include vapor deposited films of carbon, platinum, palladium, gold and the like. In addition, the method for forming the vapor deposited film is not particularly limited, and a well-known method can be used.

[0021] (2) Fly ash particle analysis step

This step is a step in which a backscattered electron image (BSE) and a chemical composition are obtained using an electron microscope from the test piece prepared in the sample preparation step. Because the electron microscope should be one capable of giving a backscattered electron image and measuring the chemical composition of extremely small regions, it is possible to use a scanning electron microscope (SEM), an electron-beam microanalyzer (EPMA), or the like. In the

backscattered electron image, brightness increases as the average atomic number of elements that constitute this region increases. Examples of apparatuses for obtaining chemical compositions include wavelength dispersion type X-Ray spectrometers (WDS) and energy dispersion type X-Ray spectrometers (EDS), but it is preferable to use an energy dispersion type X-Ray spectrometer (EDS) in order to be able to obtain a chemical composition in a short time.

In order to obtain a backscattered electron image having a high resolution, it is preferable for the accelerating voltage to be approximately 10 to 15 keV, the irradiation current to be approximately 200 to 1000 pA, and the observation magnification to be 500 to 2000 times.

[0022] When subjecting the fly ash to particle analysis, a backscattered electron image is obtained from the fly ash test piece, and a threshold value at which is possible to separate fly ash particles from the resin is determined by visually comparing the brightness with a backscattered electron image of the fly ash particles and the resin and referring to brightness histograms. In addition, fly ash particles are extracted by binarization using the threshold value. Geometrical measurement values are measured for individual extracted fly ash particles. These geometrical measurement values include coefficient of circularity, circle-equivalent diameter (the diameter of a circle having an area

equivalent to the cross sectional area of the particle), and aspect ratio and the like.

[0023] (3) Fly ash particle chemical analysis step

This step is a step in which the chemical composition of the fly ash is determined through chemical analysis of fly ash particles. In order to rapidly obtain the chemical composition of the fly ash with high precision using an energy dispersion type X-Ray spectrometer, the accelerating voltage should be approximately 10 to 15 keV, the irradiation current should be approximately 200 to 1000 pA, and the analysis time should be 5 to 10 seconds per analysis point. In addition, the analysis region size is preferably the whole of an individual particle.

Moreover, the order in which chemical analysis is carried out and geometrical measurement values are measured is not limited. In addition, the number of fly ash particles to be measured is preferably 1000 particles or more, and more preferably 2000 particles or more, in order to reduce measurement errors in the chemical analysis and the geometrical measurement values. In addition, the X-Ray count per particle is preferably 5000 or more, more preferably 10,000 or more, and further preferably 100,000 or more. For image processing reasons in the particle analysis, particles split at the edge of the image are joined together during the analysis and counted as one particle. In addition, the area

and chemical composition of particles are determined as characters per particle in the particle analysis.

[0024] (4) Fly ash particle classification step

This step is a step in which particles are classified into one of (i) particles in which iron oxide and an amorphous substance are mixed, (ii) particles in which mullite and an amorphous substance are mixed, (iii) amorphous particles not containing Ca, (iv) amorphous particles containing Ca, and (v) quartz particles, using the chemical composition of the fly ash particles and threshold values for the chemical composition of fly ash particles shown in Table 1. Moreover, extraction, chemical analysis and calculation of geometrical measurement values of fly ash particles to be subjected to classification can be measured automatically and easily using particle analysis software supplied with the electron microscope.

[0025]

[Table 1]

Classification	Chemical composition of fly ash particles				
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	SiO ₂ + Al ₂ O ₃
(i)	-	-	≥25	-	<50
(ii)	-	≥25	-	<50	≥50
(iii)	-	<25	-	<10	≥50
(iv)	-	<25	-	≥10	≥50
(v)	≥95	-	-	-	-

Note: SiO₂ + Al₂O₃ represents a simulated glass phase.

[0026] Sphere equivalent specific surface area is calculated in the following way.

First, it is assumed that all the classified fly ash particles are spheres, and the circle-equivalent diameter D is calculated from the cross sectional area S of a particle using formula (1) below.

$$D = \sqrt{\frac{4 \times S}{\pi}} \quad \cdot \cdot \cdot (1)$$

Next, on the assumption that a particle is a sphere, the surface area A and volume V of a particle are calculated from the calculated circle-equivalent diameter using formula (2) and formula (3).

$$A = \pi D^2 \quad \cdot \cdot \cdot (2)$$

$$V = \frac{\pi D^3}{6} \quad \cdot \cdot \cdot (3)$$

Finally, the sum of the volumes and the sum of the surface areas of the classified fly ash particles are calculated, and the sphere equivalent specific surface area S_A is calculated using formula (4).

$$S_A = \frac{\sum_{i=1}^n A_n}{\sum_{i=1}^n V_n} \quad \cdot \cdot \cdot (4)$$

[0027] In order to improve the workability of the ground improvement material slurry and the strength development properties of the cement composition for ground improvement,

the $(\text{Na}_2\text{O} + 0.658 \times \text{K}_2\text{O}) / (\text{MgO} + \text{SO}_3 + \text{TiO}_2 + \text{P}_2\text{O}_5 + \text{MnO})$ mass ratio in the fly ash is preferably 0.2 to 1.0, more preferably 0.25 to 0.8, further preferably 0.28 to 0.7, and particularly preferably 0.3 to 0.6.

In addition, in order to improve the workability of the ground improvement material slurry and the strength development properties of the cement composition for ground improvement, the compaction density of the fly ash, as calculated through measurements using the method described below, is preferably 1.0 to 1.5 cm³/g, more preferably 1.05 to 1.45 cm³/g, and further preferably 1.1 to 1.4 cm³/g.

[Method for measuring compaction density]

Using a PT-D powder tester produced by Hosokawa Micron Corp., compaction density is calculated by filling a 100 cm³ cup with fly ash while tapping the cup 180 times over a period of 180 seconds, and then measuring the mass of fly ash compacted in the cup. Moreover, the volume (denominator) used in the formula above for calculating density is the capacity of the cup.

[0028] Furthermore, in order to improve the strength development properties of the cement composition for ground improvement of the present invention, the cement composition may further contain one or more types of gypsum selected from among anhydrous gypsum, gypsum hemihydrate and gypsum dihydrate. The content of the gypsum is 6.0 mass% or less in terms of SO₃ if the total amount of gypsum, fly ash and

Portland cement is taken to be 100 mass%. If the content of the gypsum exceeds 6.0 mass% in terms of SO_3 , the fluidity of the ground improvement material slurry decreases. Moreover, the content of the gypsum in terms of SO_3 is more preferably 0.3 to 5.0 mass%, further preferably 0.6 to 4.0 mass% or less, and particularly preferably 1.0 to 3.0 mass%.

The gypsum is preferably anhydrous gypsum or gypsum dihydrate in order to improve the strength development properties of the cement composition for ground improvement. In addition, the Blaine specific surface area of the gypsum is preferably 3000 to 15,000 cm^2/g , and more preferably 3500 to 13,000 cm^2/g , in order to improve strength development properties.

Moreover, the cement composition for ground improvement of the present invention may further contain one or more types of inorganic powder selected from among blast furnace slag powder, limestone powder and silica stone powder as optional constituent components. Examples of apparatuses for mixing the cement composition for ground improvement include mixing devices, mixers, blenders and the like commonly used for mixing powders.

[0029] 2. Construction method for ground improvement

An explanation will now be given of the construction method for ground improvement of the present invention.

This construction method comprises improving ground by mixing soil with the ground improvement material slurry that

contains at least water and the cement composition for ground improvement.

Tap water and the like can be used as the water, and the blending quantity of the water is preferably 65 to 120 parts by mass, more preferably 70 to 110 parts by mass, further preferably 75 to 100 parts by mass, and particularly preferably 75 to 90 parts by mass, relative to 100 parts by mass of the cement composition for ground improvement. If the blending quantity of water is 65 parts by mass or more, the ground improvement material slurry and the soil can be uniformly mixed even after the slurry is stored for a relatively long period of time, and if the blending quantity of water exceeds 120 parts by mass, it may not be possible to achieve a satisfactory ground improvement effect if mixed with soil having a high water content.

In addition, in cases where the air temperature is 30°C or higher, a water-reducing agent or retarding agent may be additionally used in order to ensure the fluidity of the ground improvement material slurry. Examples of the water-reducing agent include water-reducing agents, AE water-reducing agents and high performance AE water-reducing agents commonly and the like used in cement and concrete. In addition, examples of the retarding agent include organic acids such as oxycarboxylic acids, ketocarboxylic acids, aminocarboxylic acids, polymer organic acids, salts of these acids, saccharides and sugar alcohols and the like.

In order to knead and mix the ground improvement material slurry, it is possible to use a mixer or hand mixer commonly used for kneading and mixing slurries.

[0030] 3. Ground improvement body

The ground improvement body of the present invention is improved soil obtained by mixing the ground improvement material slurry mentioned above with cohesive soil that satisfies all of conditions (S1) to (S3) above.

If ground is improved by applying the ground improvement material slurry to cohesive soil that satisfies all of conditions (S1) to (S3) above, a ground improvement body having high strength can be obtained.

[0031] The present invention will now be explained in greater detail through the use of working examples, but is not limited to these working examples.

1. Materials used

Materials used in samples are as follows.

(1) Ordinary Portland cement

Blaine specific surface area 3310 cm²/g, produced by Taiheiyo Cement Corporation.

(2) Anhydrous gypsum

Blaine specific surface area 8250 cm²/g, produced by Nacode.

(3) Water

Tap water.

In addition, characteristics of fly ash (FA) used in samples are shown in Table 2 and Table 3. Moreover, FA1 to FA5 satisfy all of conditions (F1) to (F5) above, but FA6 to FA8 do not satisfy some of these conditions. Furthermore, FA1 does not satisfy condition (F6) and FA2 does not satisfy condition (F7), but FA3 and FA4 satisfy both (F6) and (F7). In addition, the sphere equivalent specific surface area of quartz particles in FA5 falls outside the range 1100 to 12,500 cm^2/cm^3 .

[0032]

[Table 2]

Type of fly ash	Blaine specific surface area (cm^2/g)	Mass reduction rate (mass%)	SiO_2 content (mass%)	Fe-G (cm^2/cm^3)	CAS (cm^2/cm^3)
FA1	3880	3.1	57.3	7690	4100
FA2	3800	3.2	58.5	7560	11,820
FA3	3660	3.4	54.8	5630	18,160
FA4	3020	3.7	58.3	10,560	14,290
FA5	3500	2.5	51.3	3430	7360
FA6	2300	2.9	53.3	6320	5810
FA7	3160	7.2	53.8	7350	5300
FA8	3360	4.2	46.8	2670	1570

Note: Fe-G indicates the sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed, and CAS indicates the sphere equivalent specific surface area of amorphous particles containing Ca.

[0033]

[Table 3]

Type of fly ash	M-G (cm ² /cm ³)	AS (cm ² /cm ³)	Q (cm ² /cm ³)
FA1	1300	8860	8600
FA2	8840	9430	9120
FA3	4660	7630	8160
FA4	9020	8560	4200
FA5	3500	3430	16,000

Note: M-G indicates the sphere equivalent specific surface area of particles in which mullite and an amorphous substance are mixed.

Note: AS indicates the sphere equivalent specific surface area of amorphous particles not containing Ca.

Note: Q indicates the sphere equivalent specific surface area of quartz particles.

[0034] 2. Production of cement compositions for ground improvement

Cement compositions were produced by mixing fly ash (FA), cement (C) and anhydrous gypsum (G) as an optional component according to formulations shown in Table 4.

[0035]

[Table 4]

	Cement composition formulation				
	Type of FA	FA (mass%)	C (mass%)	G	
				(mass%)	In terms of SO ₃

Working Example 1	FA1	20	80	0	0
Working Example 2	FA2	20	80	0	0
Working Example 3	FA3	20	80	0	0
Working Example 4	FA4	20	80	0	0
Working Example 5	FA5	20	80	0	0
Working Example 6	FA2	10	90	0	0
Working Example 7	FA2	40	60	0	0
Working Example 8	FA2	20	79	1	0.6
Working Example 9	FA2	20	78	2	1.2
Working Example 10	FA2	20	76	4	2.4
Comparative Example 1	-	-	100	0	0
Comparative Example 2	-	-	99	1	0.6
Comparative Example 3	-	-	98	2	1.2
Comparative Example 4	-	-	96	4	2.4
Comparative Example 5	FA6	20	80	0	0

Comparative Example 6	FA7	20	80	0	0
Comparative Example 7	FA8	20	80	0	0
Comparative Example 8	FA2	5	95	0	0
Comparative Example 9	FA2	50	50	0	0

In other words, in Table 3,

(i) Working Examples 1 to 7 are cement compositions of the present invention in which the content of fly ash falls within the range 10 to 40 mass% if the total amount of Portland cement and fly ash FA1 to FA5, which satisfy all of conditions (F1) to (F5) above, is taken to be 100 mass%.

(ii) Working Examples 8 to 10 are cement compositions of the present invention in which anhydrous gypsum is mixed at a quantity of 6 mass% or less in terms of SO₃.

(iii) Comparative Examples 1 to 4 are cement compositions that do not contain fly ash.

(iv) Comparative Examples 5 to 7 are cement compositions that contain FA6 to FA8, which do not satisfy some of conditions (F1) to (F5) above.

(v) Comparative Examples 8 and 9 are cement compositions in which the content of fly ash falls outside the range 10 to 40 mass%.

[0036] 3. Measurement of usable time of ground improvement material slurry

At an environment temperature (ambient temperature) of 27°C, 1.5 kg of water and 2 kg of a (powdered) cement composition for ground improvement shown in Table 2 (a water/powder ratio of 75%) were placed in a 5 L plastic cup, and kneaded and mixed for 2 minutes using a hand mixer so as to produce a ground improvement material slurry, and the flow-down time of the slurry in a P-funnel was measured twice, and the average of these measurement values was determined.

Next, the ground improvement material slurry was returned to the 5 L plastic cup, tightly sealed with a wrapping film in order to prevent dissipation of moisture, and left to stand. After standing for 2 hours and 3 hours, the ground improvement material slurry was kneaded and mixed in the same way using the hand mixer, after which the flow-down time of the slurry in a P-funnel was measured again in the same way, and the change over time in flow-down time after kneading and mixing was determined. On the basis of statements in Document A below, if the flow-down time in a P-funnel 3 hours after kneading and mixing is 12 seconds or longer, this is assessed as a fail.

Document A: "Engineering Characteristics and Future Prospects of Improved Soil By FGC Deep Mixing Method using Coal Ash", Proceedings of the 6th Conference on Coal Usage Technology, pp 145 to 157, 1996

[0037] 4. Measurement of strength of ground improvement body

A ground improvement material slurry was produced by placing 10 kg of a cement composition for ground improvement and 7.5 kg of water (a water/powder ratio of 75%) in a bucket and kneading and mixing using a hand mixer.

Next, the slurry and volcanic ash cohesive soil (Kanto loam), in which the water/powder ratio was 75.1%, the allophane content measured using an acidic oxalate extraction method was 18.3% and the Ca(OH)_2 adsorption amount was 90 mg, were mixed at a temperature of 20°C in accordance with Japanese Geotechnical Society standards (JGS0821-2009) "Practice for Making and Curing Stabilized Soil Specimens without Compaction", thereby producing a specimen of a ground improvement body having a diameter of 5 cm and a height of 10 cm.

Next, produced specimens were aged for 7 days, 28 days and 91 days, after which uniaxial compressive strength was measured in accordance with JIS A 1216 "Uniaxial-Compression Test Methods for Soils", and strength development properties were confirmed.

Moreover, with regard to uniaxial compressive strength, it is assumed on the basis of statements in Document B below that the (work site/indoor) strength ratio in an indoor blending test is 0.5 relative to a uniaxial compressive strength of 50 to 100 kN/m^2 following improvement, which is a common requirement for improvement of generated soil, and a

maximum value of 200 (= 100/0.5) kN/m² or more was taken to be a pass.

Document B: "Ground improvement manual using cement-based solidification material (4th edition)" (published by the Japan Cement Association)

Measurement results for P-funnel flow-down times and uniaxial compressive strength are shown in Table 5.

[0038]

[Table 5]

	P-funnel flow-down time (sec)			Uniaxial compressive strength (kN/m ²)		
	Immediate	After 2 hours	After 3 hours	Material age 7 days	Material age 28 days	Material age 91 days
Working Example 1	10.6	10.8	11.1	149	243	290
Working Example 2	10.5	10.6	11.0	151	248	291
Working Example 3	10.6	10.8	11.1	148	241	276
Working Example 4	10.2	10.4	10.9	145	260	301
Working Example 5	10.5	10.5	10.9	150	242	274
Working Example 6	10.7	10.9	11.4	155	263	300
Working Example 7	10.0	10.1	10.3	110	203	213

Working Example 8	10.5	10.6	11.0	248	235	287
Working Example 9	10.6	10.6	11.0	328	355	414
Working Example 10	10.7	10.7	11.2	525	688	787
Comparative Example 1	10.5	10.8	12.2	220	298	448
Comparative Example 2	10.6	10.7	12.4	385	490	571
Comparative Example 3	10.5	10.8	12.5	402	629	666
Comparative Example 4	10.7	10.8	12.8	792	1067	1147
Comparative Example 5	10.5	10.6	11.2	142	198	185
Comparative Example 6	10.5	10.6	11.1	145	188	191
Comparative Example 7	10.5	10.7	11.3	149	196	210
Comparative Example 8	10.5	10.7	12.2	220	298	448
Comparative Example 9	10.0	10.1	10.2	110	153	181

[0039] 5. Evaluation of measurement results

(i) Fluidity retention time

As shown in Table 5, ground improvement material slurries obtained using cement compositions for ground improvement of the present invention (Working Examples 1 to

10) had P-funnel flow-down times of 12 seconds or less after 3 hours after kneading and mixing, and had long fluidity retention times at an environment temperature of 27°C.

Conversely, slurries obtained using cement compositions of Comparative Examples 1 to 4 and Comparative Example 8 tended to have short fluidity retention times at an environment temperature of 27°C.

(ii) Uniaxial compressive strength

Uniaxial compressive strengths at a material age of 28 days of ground improvement bodies obtained using cement compositions for ground improvement of the present invention (Working Examples 1 to 10) all exceeded 200 kN/m², and Working Examples 8 to 10 in particular exhibited similar strength enhancement to ordinary Portland cement (Comparative Example 1) through addition of gypsum, and could ensure a suitable usable time.

Conversely, Comparative Examples 5 to 7 exhibited less strength enhancement than Working Examples 1 to 10, and Comparative Examples 2 to 4 exhibited enhanced strength through addition of gypsum, but had longer flow-down times and could not ensure a suitable usable time in warm climates and regions.

[CLAIMS]

[Claim 1]

A cement composition for ground improvement, which contains at least fly ash that satisfies all of conditions (F1) to (F6) below and Portland cement, wherein a content of the fly ash is 10 to 40 mass% when a total amount of the fly ash and the Portland cement is 100 mass%:

(F1) a Blaine specific surface area of the fly ash is 2500 to 6000 cm²/g;

(F2) a mass reduction rate of the fly ash is 5 mass% or less after the fly ash is heated for 15 minutes at a temperature of 975 ± 25°C;

(F3) a content of SiO₂ in the fly ash is 50 mass% or more;

(F4) in the fly ash, a sphere equivalent specific surface area of particles in which iron oxide and an amorphous substance are mixed is 2800 to 11,000 cm²/cm³; and

(F5) in the fly ash, a sphere equivalent specific surface area of amorphous particles containing Ca (calcium) is 2100 to 22,500 cm²/cm³;

(F6) in the fly ash, a sphere equivalent specific surface area of particles in which mullite and an amorphous substance are mixed is 1900 to 9500 cm²/cm³.

[Claim 2]

The cement composition for ground improvement according to claim 1, wherein the fly ash also satisfies condition (F7) below:

(F7) in the fly ash, a sphere equivalent specific surface area of amorphous particles not containing Ca is 2100 to 9000 cm²/cm³.

[Claim 3]

The cement composition for ground improvement according to any one of claim 1 or claim 2, which further contains one or more types of gypsum selected from among anhydrous gypsum, gypsum hemihydrate and gypsum dihydrate, wherein

a content of the gypsum is 6.0 mass% or less in terms of SO₃ when a total amount of Portland cement, fly ash and the gypsum is 100 mass%.

[Claim 4]

A construction method for ground improvement, wherein ground is improved by mixing soil with a ground improvement material slurry that contains at least water and the cement composition for ground improvement according to any one of claims 1 to 3.

[Claim 5]

A ground improvement body obtained by mixing the ground improvement material slurry according to claim 4 with cohesive soil that satisfies all of conditions (S1) to (S3) below:

(S1) a moisture content is 70 to 150%;

(S2) an allophane content, as measured using an acidic oxalate extraction method, is 5.0% or more; and

(S3) when cohesive soil is mixed with a slurry containing 150 mg of $\text{Ca}(\text{OH})_2$ and 100 ml of water, an amount of $\text{Ca}(\text{OH})_2$ adsorbed by the cohesive soil is 80 mg or more per 1 g of the cohesive soil.