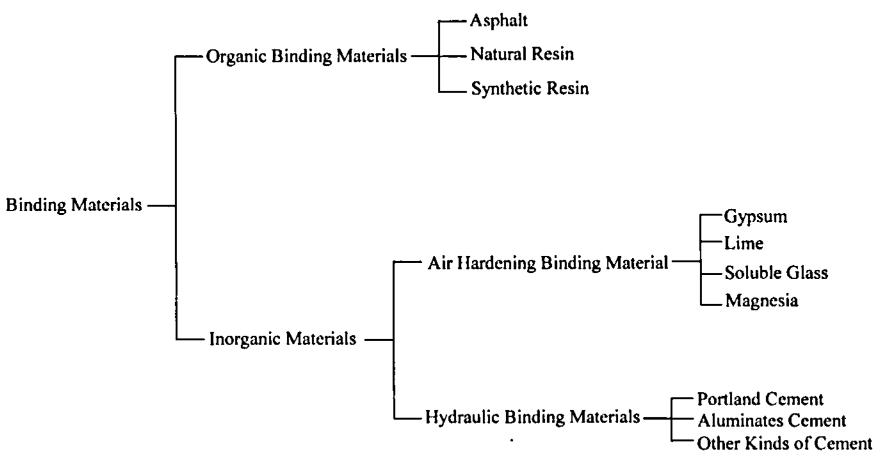
3

Air Hardening Binding Materials

This chapter mainly introduces the characteristics, technical requirements and applications of lime, gypsum, magnesia, and sodium silicate.

In construction projects, the materials that can conglutinate granular materials (such as sand and gravel) or bulk materials (such as bricks and stone) together as a whole are called binding materials, the important materials in construction projects. And the common binding materials can be divided into:



This chapter will introduce several air-hardening binding materials commonly used in construction projects. Such materials can only be hardened in the air (dry conditions) and their strength can maintain and develop only in the air.

3.1 Building Gypsum

Gypsum is an air-hardening materials mainly consisting of calcium sulfate. And its products have many excellent characters, commonly used in construction. There are various kinds of gypsum binding materials, such as building gypsum, high-strength gypsum, anhydrite cement, and high-temperature-calcined gypsum.

3.1.1 The Introduction of Building Gypsum Production

The raw materials to produce gypsum cement materials are natural dihydrate gypsum ($CaSO_4 \cdot 2H_2O$), natural anhydrite ($CaSO_4$), and chemical by-products composed of $CaSO_4 \cdot 2H_2O$ or $CaSO_4 \cdot 2H_2O$ and $CaSO_4$.

The gypsum used in construction is semi-hydrated gypsum ($CaSO_4 \cdot \frac{1}{2} H_2O$) processed by natural bihydrate gypsum, also known as calcined gypsum. Varieties of gypsum will be produced when the natural dihydrate gypsum is processed with the change of heating methods and temperatures. The main production procedures are breaking, heating and grinding.

The gypsum commonly used in construction projects is building gypsum, composed of β semi-hydrate gypsum. The natural dihydrate gypsum is calcined into semi-hydrate gypsum under the temperature of 107 ~ 170 ℃ and then is ground into powder which is the building gypsum. Its reactive mode is:

$$CaSO_4 \cdot 2H_2O + \xrightarrow[\text{air heating}]{107\sim170^{\circ}C} CaSO_4 \cdot \frac{1}{2} H_2O + \frac{1}{2} H_2O$$

3.1.2 Technical Requirements of Building Gypsum

Building gypsum is white and of 2.6~2.75g/cm^3 density and 800~1000kg/m^3 bulk density.

According to GB9776-88, building gypsum can be classified into high-class, first-class and acceptable grades in light of strength, fineness and setting time, shown in Table 3.1. Among them, bending strength and compressive strength are measured by letting samples contact with water for 2 hours.

Table 3.1 Technical Indicators of Building Gypsum

Indicators \ Grades		High-class	First-class	Acceptable
Strength (MPa)	Bending Strength (≥)	2.5	2.1	1.8
	Compressive Strength (≥)	4.9	3.9	2.9
Fineness (%)	Sieve Residue of 0.2mm Square-hole Sieve (≤)	5.0	10.0	15.0
Setting Time (min)	Initial Setting Time (≤)	6		
	Final Setting Time (≤)	30		

Building gypsum is tagged by the order of name, bending strength and standard number. For example, the building gypsum of 2.5MPa bending strength can be tagged as: Building Gypsum 2.5 GB 9776.

The hydration of building gypsum technically requires that water requirements accounts for 18.6% of the weight of semi-hydrate gypsum. But in fact, water often accounts for 60%~80% in order to make the gypsum slurry have certain plasticity. The excess water gradually evaporates in the hardening process, which leads to a large number of pores left in the hardened gypsum, with the porosity of 50%~60%. Thus, building gypsum has low strength, small apparent density, low thermal conductivity and high sound absorption after hardening.

In the process of storage and transport, building gypsum should not be exposed to moisture and mixed with sundries. Gypsum of different grades should be stored respectively and should not be mixed. The general storage period is three months. And the strength will reduce by 30% over 3 months. The gypsum beyond storage period needs to be re-examined to determine the grades.

3.1.3 The Hardening Mechanics of Building Gypsum

Mixed with water, building gypsum can be modulated into plastic slurry. And after a period of reaction, it will lose plasticity and condense into solid with certain strength.

The setting and hardening of building gypsum occur because water and semi-hydrate gypsum react mutually and then restore to dihydrate gypsum:

$$CaSO_4 \cdot \frac{1}{2} H_2O + 1\frac{1}{2} H_2O = CaSO_4 \cdot 2H_2O$$

Semi-hydrate gypsum dissolves in water and turns into a saturated solution soon. Combining with water, the semi-hydrate gypsum in the saturated solution becomes dihydrate gypsum. The saturated solution of semi-hydrate gypsum is oversaturated for dihydrate gypsum because the solubility of dihydrate gypsum is much smaller than that of semi-hydrate gypsum. Thus, the saturated solution precipitates the dihydrate gypsum in the form of colloid particle, which accelerates the semi-hydrate gypsum to dissolve and hydrate continuously till complete dissolution. In this process, the free water in the slurry decrease gradually because of hydration and evaporation, the colloid particles of dihydrate gypsum increase, the consistency of the slurry rises, and friction and cohesive forces between particles grow increasingly. Therefore, the plasticity of the slurry decrease gradually, called "setting". Subsequently, the slurry continues getting thicker, and colloid particles gradually turn into crystals. They become bigger, symbiotic and staggered, which enable the slurry to have strength. Such strength continues growing till complete dryness, and friction and cohesive forces between crystals stop increasing. At this moment, the strength stops developing. This whole process is called "hardening". In fact, setting and hardening of gypsum are continuous and complicated physical and chemical processes.

3.1.4 Characteristics of Building Gypsum

Compared with other binding materials, building gypsum has the following characteristics:

1. Fast Setting and Hardening

The setting time of building gypsum changes with the calcination temperature, grinding rate and impurity content. Generally, mixed with water, its initial setting needs just a few minutes at room temperature, and its final setting is also within 30min. Under the natural dry indoor conditions, total hardening needs about one week. The setting time can be adjusted according to requirements. If the time needs to be postponed, delayed coagulant can be added to reduce the solubility and the solution rate of building gypsum, such as sulfite alcohol wastewater, bone glue activated by borax or lime, hide glue, and protein glue; if it needs to be accelerated, accelerator can be added, such as sodium chloride, silicon sodium fluoride, sodium sulfate, and magnesium sulfate.

2. Micro-expansion

In the hardening process, the volume of building gypsum just expands a little, and there won't be any cracks. Thus, it can be used alone without any extenders, and can also be casted into construction members and decorative patterns with accurate size and smooth and compact surface.

3. Big Porosity

After hardening, the porosity of building gypsum can reach 50%~60%, so its products are light, insulating, and sound-absorbing. But these products have low strength and large water absorption due to big porosity.

4. Poor Water Resistance

Building gypsum has low softening coefficient (about 0.2~0.3) and poor water resistance. Absorbing water, it will break up with the freeze of water. Thus, its water resistance and frost resistance are poor, not used outdoors.

5. Good Fire Resistance

The main component of building gypsum after hardening is $CaSO_4 \cdot 2H_2O$. When it contacts with fire, the evaporation of crystal water will absorb heat and generate anhydrous gypsum which has good thermal insulation. The thicker its products are, the better their fire resistance will be.

6. Large Plastic Deformation

Gypsum and its products have an obvious performance of plastic deformation. Creep becomes more serious especially under bending load. Thus, it is not used for load-bearing structures normally. If it is used, some necessary measures need to be taken.

3.1.5 Applications of Building Gypsum

As mentioned above, building gypsum has excellent performance. It is suitable for indoor decoration, insulation and thermal retardation, sound absorption, and fire retardation. Generally, it is made into plaster mortar, architectural and decorative products, and gypsum plank.

1. Indoor Plastering and Painting

Mixed with water and sand, building gypsum will turn into gypsum mortar which can be used for indoor plastering. Such plastered wall is insulating, fire-resistant, sound-absorbing, comfortable, and aesthetic. The plastered wall and ceiling can be painted or pasted with wallpaper directly.

The gypsum mortar can be used as indoor coating material mixed with lime. The wall painted with this mortar is smooth, delicate, white, and beautiful.

Plastering gypsum should accord with *The Plastering Gypsum* (JC/T517-93), the industrial standard. And its main technical indexes are as follows: fineness: if it passes through the square-hole sieve of 25mm, there is no residue, and through the square-hole sieve of 0.2mm, the residue $\leqslant 40\%$; bending strength: that of the excellent plastering gypsum is 3.0MPa, and that of the first-class one is 2.0MPa; compressive strength: that of the excellent plastering gypsum is 5.0MPa, and that of the first-class one is 3.5MPa; setting time: the initial one ⩾ 60min, and the final one ⩾8h.

2. Decorative Products

As the main raw material, gypsum will be stirred into gypsum mortar with water, added a small amount of fiber-reinforced materials and plastic materials. By its micro-expansion performance, the gypsum mortar can be made into various plaster sculptures, decorative panels and accessories.

3. Gypsum Plank

China's current gypsum planks mainly include thistle board, decorative plaster plate, fibrous plaster board and others.

(1) Thistle Board

It uses gypsum as the core material and paper as the surface on the two sides. It is of 900~1200mm width and 9~12mm thickness. The length can be fixed according to needs. The thistle board is mainly used as inner wall, partition wall, and ceiling.

(2) Hollow Gypsum Strip

It uses building gypsum as the main raw material, specification for: (2500 ~ 3500) mm × (450 ~ 600) mm × (60 ~ 100) mm, 7 ~ 9 holes, and hole ratio of 30%~40%. This board has high strength which can be used as the inner wall and partition wall in residential and public buildings. And its installation does not need any keel.

(3) Decorative Plaster Plate

Building gypsum is the main raw material of decorative plaster board, specifications for square with the side of 300mm,400mm,500mm,600mm and 900mm. There are flat plates, porous plates, diamond plates, embossed plates and decorate plates which are diverse, colorful, and aesthetic, mainly used as walls and ceilings in public buildings.

(4) Fibrous Plaster Board

This board uses building gypsum, cardboard and short glass fiber as the main raw materials. With high bending strength, it can be used as inner wall and partition wall, or be used to make furniture instead of wood.

Besides, there are cellular gypsum boards, moisture-resistant gypsum boards, and compound mine-wool boards which can be used as thermal insulation panels, acoustic panels, inner walls, partition walls, ceilings, and floor basal plates.

If supported by fiber-reinforced materials and gelling agents, building gypsum can be made into gypsum coving, line board, corner pattern, lamp ring, Roman column, sculptures and other artistic gypsum products.

3.2 Lime

Lime is one of the earliest binding materials used in buildings because its raw materials are rich and widely distributed, the production process is simple and low-cost, and it is easy to use. Therefore, lime is still widely used in construction until now.

3.2.1 The Introduction of Lime Production

1. Raw Materials of Lime

The main raw material of lime is natural rock whose major component is calcium carbonate. The common lime includes limestone, dolomite, and chalk. These natural raw materials often contain clay impurities whose content should be controlled within 8%.

Besides the natural raw materials, another source of lime is the chemical industrial by-products. For example, the major component of the carbide slag remained in the preparation of acetylene from acetylene stone (calcium carbide) is calcium hydroxide, namely, hydrated lime.

2. Lime Production

After calcination, limestone generates quicklime. The reactive mode is:

$$CaCO_3 \xrightarrow{900℃} CaO+CO_2$$

In actual production, the calcination temperature is often controlled within 1000~1100℃ in light of the heat loss because limestone's dense degrees, sizes of block, and impurities are different. If the calcination temperature is too low and the calcination time is not sufficient, $CaCO_3$ cannot dissolve completely and will generate under-burnt lime. Under-burnt lime generates less mortar and the quality is poor, which lowers the utilization of lime; if the calcination temperature is too high, the dark-color over-burnt lime with high density will be generated which will affect the project quality.

Quicklime is a kind of white or grey block substance whose major component is CaO. The calcinated lime contains MgO correspondingly because its raw materials always contain some magnesium oxide components. According to JC/T480-92 *Building Quicklime* provision, the standard of China's building material industry, when the content of MgO is smaller than or equal to 5%, it is called calcium quicklime; when the content of MgO is bigger than 5%, it is called magnesia quicklime.

3. Aging of Lime

The process that quicklime (CaO) generates calcium hydroxide with water is known as the aging or digestion process of lime, of which the reactive mode is:

$$CaO+H_2O=Ca(OH)_2+64.9kJ/mol$$

The aging of lime releases much heat, and the volume of lime expands 1~2.5 times.

The theoretical water demand needed in the aging process takes only 32.1% of lime's mass. But the actual water demand (60%~80%) is more because part of the water will evaporate. If too much water is added, the temperature will drop and the aging process will slow down, which will extend the aging time. There are two methods used for lime aging on construction site: slurry process and powder process of hydrated lime.

Quicklime often contains over-burnt lime which is the fused mass with dark brown surface. The aging of over-burnt lime is very slow and the over-burnt particles start to age when lime has gotten hardened. Then the volume expands, leading to uplifting and cracking. In order to eliminate the destruction caused by over-burnt lime, lime mortar has to "be stabilized" in the lime storage pool for more than two weeks. In the period of "stabilization", there is a layer of water on the surface of lime mortar, and the lime mortar is isolated from air to prevent the carbonization of lime.

3.2.2 The Hardening of Lime

The hardening of lime in the air includes two processes:

1. Crystallization

In the use of lime mortar, $Ca(OH)_2$ solution is over-saturated and gradually precipitate crystals because the free water gradually evaporates and is absorbed by masonry. This process accelerates the hardening of lime mortar and meantime the mortar tightens and generates strength due to dryness.

2. Carbonization

With CO_2 in the air, $Ca(OH)_2$ generates the insoluble crystals of calcium carbonate, and the precipitated water gradually evaporates. The reactive mode is as follows:

$$Ca(OH)_2+CO_2+nH_2O=CaCO_3+(n+1)H_2O$$

This process is known as carbonization. And the precipitated $CaCO_3$ crystals make the hardened mortar compact and enhance the strength.

The content of CO_2 in the air is little. And carbonization mainly happens on the surface, contacting with the air. And the compact $CaCO_3$ film generated on the surface hinders the further infiltration of the air and prevents the inner water evaporating, which slow down the crystallization of $Ca(OH)_2$. As time passes, the thickness of $CaCO_3$ on the surface increases and the prevention become greater. In quite a long period, $CaCO_3$ is still the surface and $Ca(OH)_2$ is inside, so the hardening process of lime is very slow.

3.2.3 Technical Requirements of Lime

The lime used in construction can be divided into three varieties: building quicklime, building quicklime powder, and building hydrated lime powder. They can be classified into three grades respectively, according to the standards of the building industry, and the corresponding indexes are listed in Table 3.2, Table 3.3 and Table 3.4.

The product whose various technical indexes reach a certain grade set in the tables should be targeted with this grade. If one of its technical indexes is less than the qualified grade, it should be targeted as the ineligible product.

Table 3.2 Technical Indexes of Building Quicklime

Item	Calcium Quicklime			Magnesia Quicklime		
	High-class	First-class	Acceptable	High-class	First-class	acceptable
CaO+MgO content (%) (≥)	90	85	80	85	80	75
Residue (residue of 5mm round hole sieve) (%) (≤)	5	10	15	5	10	15
CO_2 (%) (≤)	5	7	9	6	8	10
Mortar Production (L/kg) (≥)	2.8	2.3	2.0	2.8	2.3	2.0

Table 3.3 Technical Indexes of Building Quicklime Powder

Item		Calcium Quicklime Powder			Magnesia Quicklime Powder		
		High-class	First-class	Acceptable	High-class	First-class	Acceptable
CaO+MgO content (%) (≥)		85	80	75	80	75	70
CO_2 (%) (≤)		7	9	11	8	10	12
fineness	Residue of 0.9mm Sieve (%) (≤)	0.2	0.5	1.5	0.2	0.5	1.5
	Residue of 0.125mm Sieve (%) (≤)	7.0	12.0	18.0	7.0	12.0	18.0

Table 3.4 Technical Indexes of Building Hydrated Lime Powder

Item		Calcium Quicklime Powder			Magnesia Quicklime Powder
		High-class	First-class	Acceptable	High-class
CaO+MgO content (%) (≥)		70	65	60	65
Free Water (%)		0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2
Volume Stability		Acceptable	Acceptable	—	Acceptable
fineness	Residue of 0.9mm Sieve (%) (≤)	0	0	0.5	0
	Residue of 0.125mm Sieve (%) (≤)	3	10	15	3

Item		Magnesia Quicklime Powder		Dolomite Hydrate Lime Powder		
		First-class	Acceptable	High-class	First-class	Acceptable
CaO+MgO content (%) (≥)		60	55	65	60	55
Free Water (%)		0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2
Volume Stability		Acceptable	—	Acceptable	Acceptable	—
fineness	Residue of 0.9mm Sieve (%) (≤)	0	0.5	0	0	0.5
	Residue of 0.125mm Sieve (%) (≤)	10	15	3	10	15

3.2.4 Characteristics of Lime

1. Good Water Retention

The lime mortar generated by the aging of lime has good water retention, so it can be mixed in cement mortar to improve the water retention of mortar to facilitate construction.

2. Slow Setting and Hardening, Low Strength

Because the carbonization of lime mortar in the air is very slow, the production of calcium carbonate and calcium hydroxide is a little and quite slow. And thus, the strength of hardened lime is low. According to tests, 1 : 3 lime mortar of 28d has only 0.2~0.5 MPa strength which should not be the basis for important buildings.

3. Poor Water Resistance

Calcium hydroxide is soluble in water, so if it is exposed to moisture or immerses in water for a long time, the hardened lime will scatter. If lime mortar is in humid environment before complete hardening, the water in lime cannot evaporate, and the hardening will be hindered. Therefore, lime should not be applied in humid environment.

4. Large Shrinkage

In the hardening process of lime mortar, a large amount of water evaporates, which cause the shrinkage of volume. And desiccation cracks will appear. Thus, lime mortar should not be used alone except for the lime cream for thin painting. In use, it is often mixed with sand, hemp fiber, paper pulp, and other things to resist cracking caused by shrinkage.

3.2.5 Applications and Storage of Lime

After being processed, quicklime can generate many varieties of lime, such as quicklime powder, hydrated lime powder, lime cream, and lime paste. And different varieties have different purposes.

1. Lime Powder

Lime powder can be made into silicate products mixed with materials containing silicon. With water, pulverized lime can be molded by being mixed with fiber materials (such as glass fiber) or lightweight aggregate. Then, it can be carbonized artificially with carbon dioxide for carbonized lime board. Carbonized lime board has a good processing property, suitable for the non-load-bearing inner partition and ceiling. Mixed with a certain percentage of clay, pulverized lime can generate limestone soil. Triple-combined soil can be generated by mixing lime powder with clay, gravel, and slag. Lime soil and triple-combined soil are mainly used for foundation, bedding cushion, and roadbed.

2. Lime Paste

The aged lime paste or hydrated lime can turns into lime milk, diluted with water, as paint of internal and external walls and ceilings; if mixed with a certain amount of sand or cement and sand, it can be prepared into lime mortar or compound mortar for masonry or finishing; it can be used to paint inner walls or ceilings by being mixed with paper pulp and hemp fiber.

3. Storage of Lime

Quicklime will absorb the water and carbon dioxide in the air, generate calcium carbonate powder and lose cohesive force. Thus, when stored on construction site, quicklime should not be exposed to moisture, not be more, and not stay for a long time. Moreover, the aging of lime will release a great amount of heat, so quicklime and inflammable matter should be stored separately in order to avoid fire. Usually quicklime should be stabilized immediately and the storage period should be changed into aging period.

3.3 Magnesia

Magnesia is an air hardening binding material. Its major component is magnesium oxide (MgO) which is a kind of white or yellow powder, belonging to magnesia cement materials. Its main raw material comes from natural magnesite ($MgCO_3$) and can also be extracted from serpentine ($3MgO \cdot 2SiO_2 \cdot 2H_2O$), dolomite ($MgCO_3 \cdot CaCO_3$), molten slag produced by smelting magnesium alloy (the content of MgO is not less than 25%), or seawater.

$MgCO_3$ in magnesite starts to decompose at 400℃ and reacts fiercely at 600~650℃. The calcination temperature is usually controlled at 750 ~ 850℃ when magnesia is generated. The reactive mode is as follows:

$$MgCO_3 \longrightarrow MgO + CO_2\uparrow$$

Magnesia will be gotten by grinding the block remained after calcination. Its density is 3.10～3.40g/cm^3 and bulk density is 800～900kg/m^3.

Magnesia should not be exposed to moisture in transport or storage and also cannot be stored for a long time. Because by absorbing the water in the air, magnesia turns into $Mg(OH)_2$ and then is carbonized into $MgCO_3$, finally losing its chemical activity.

In addition, dolomite ($MgCO_3 \cdot CaCO_3$) calcinated at 650~750 ℃ will generate a mixture composed of MgO and $CaCO_3$, known as caustic dolomite:

$$MgCO_3 \cdot CaCO_3 \longrightarrow MgO + CaCO_3 + CO_2\uparrow$$

Caustic dolomite also belongs to magnesia cement materials and has similar property and purpose with magnesia.

3.3.1 The Hardening of Magnesia

When magnesia is stirred with water, MgO reacts with water and generates $Mg(OH)_2$, releasing a lot of heat:

$$MgO + H_2O \longrightarrow Mg(OH)_2$$

When slurry is made with water, setting and hardening are very slow and the strength after hardening is very low. Thus, modifier is always used to accelerate the hardening process. The most common modifier is magnesium chloride solution, and the reaction is:

$$x MgO + y MgCl_2 \cdot 6H_2O \longrightarrow x MgO \cdot y MgCl_2 \cdot z H_2O$$

$$MgO + H_2O \longrightarrow Mg(OH)_2$$

The magnesium oxychloride ($x MgO \cdot y MgCl_2 \cdot z H_2O$) and Mg $(OH)_2$ generated by reaction precipitate from solution gradually, and condense and crystallize to harden the slurry. After adding modifier, setting and hardening will become faster, and also the strength will be improved markedly.

3.3.2 Technical Properties of Magnesia

According to JC/T449-91, magnesia can be divided into high-class grade (A), first-class grade (B) and acceptable grade (C) by the chemical and physical properties, and the main technical properties are listed in Table 3.5.

Table 3.5 The Technical Indexes of Magnesia

		High-class (A)	First-class (B)	Acceptable (C)
MgO (%) (≥)		80	75	70
Free CaO (%) (≤)		2	2	2
Residue of 0.08mm Square-hole Sieve (%)(≤)		15	15	20
Setting Time	Initial (min) (≥)	40	40	40
	Final (h) (≤)	7	7	7
Bending Strength (MPa) (≥)	1d	5.0	4.0	3.0
	3d	7.0	6.0	5.0
Compressive Strength (MPa) (≥)	1d	25.0	20.0	15.0
	3d	30.0	25.0	20.0

3.3.3 Applications of Magnesia

Magnesia and plant fibers bind strongly, which can avoid decomposition of fibers. Therefore, it is always mixed with wood chips and wood fibers to produce xylolite floor, wood-cement board, and xylolite slab.

In addition to wood chips and wood fibers, French chalk, asbestos, fine quartz sand, brick powder and other fillers are added to magnesia in order to improve the strength and wear resistance of products. Magnesia grindstone floor will be made by using marble or rock of medium hardness as the aggregate.

Magnesia floor is heat-retardate, dust-free, wear-resistant, fire-resistant, smooth, and elastic. It is a good floor material that can be colored by adding alkali-resistant mineral pigments.

Magnesia board has high tightness, high intensity, sound absorption and thermal insulation, which can be used as the inner wall, ceiling and other building materials.

Reinforced magnesia has high intensity and can be used as constructional element instead of wood, such as wood pad and column.

Magnesia can be made into light and porous thermal-insulating material by adding foaming agent.

The water resistance of magnesia is poor, so its products should not be stored in humid places for a long time. And its products should not be used with steel bars, for in the process of using magnesia, magnesium chloride solution is commonly used and the chloride ions can erode steel bars.

3.4 Soluble Glass

Soluble glass, also called foam alkali, is an alkali metal air hardening material. In construction, it is usually used to prepare sodium silicate cement, soluble glass mortar, and soluble glass concrete. Soluble glass is widely used in the anti-acid and heat-resistant engineering.

3.4.1 The Introduction of Soluble Glass

The main method to produce soluble glass is to grind and stir calcined soda and quartz sand which are the major raw materials, then fuse them in the melting pot of 1300~1400℃, and finally cool them into solid soluble glass. The reactive mode is as follows:

$$NaCO_3+nSiO_2 \xrightarrow{1300\sim1400℃} Na_2O\cdot nSiO_2+CO_2\uparrow$$

Liquid soluble glass is obtained in the way of stuffing solid soluble glass into autoclave and dissolving it by steaming, or putting quartz sand solution and sodium hydroxide solution into autoclave (20~30kPa), heating them by steam and stirring the solutions to make them react directly. Liquid soluble glass is alkali. Pure soluble glass solution should be clear and colorless liquid, but it often appears steel grey or yellow-green due to impurities.

3.4.2 The Hardening of Soluble Glass

Soluble glass solution absorbs carbon dioxide in the air to generate amorphous silicate and gradually becomes dry till hardening.

$$Na_2O\cdot nSiO_2+CO_2+mH_2O=Na_2CO_3+nSiO_2\cdot mH_2O$$

The process is very slow. In the using process, soluble glass is often heated or mixed with sodium fluosilicate (Na_2SiF_6) as an accelerator for hardening to quicken the hardening speed. Sodium fluosilicate is added into soluble glass will react as follows, speeding up the precipitation of silicic acid gel.

$$2[Na_2O\cdot nSiO_2]+Na_2SiF_6+mH_2O=6NaF+(2n+1)SiO_2\cdot mH_2O$$

The appropriate amount of sodium fluosilicate should account for 12%~15% of the weight of soluble glass. Sodium fluosilicate can also improve the water resistance of soluble glass.

3.4.3 Characteristics of Soluble Glass

According to the differences of alkali metal oxide, soluble glass can be divided into sodium silicate and potassium silicate, and sodium silicate is often used. Among the components of sodium silicate ($Na_2O\cdot nSiO_2$), the ratio of silicon oxide molecules to sodium oxide molecules (represented by "n") is known as the module of soluble glass, generally between 1.5 to 3.5. And the number of module decides the properties and performance of soluble glass. The solid soluble glass with low module is relatively easy to dissolve in water. The bigger the number is, the higher the viscosity is and the harder it dissolves in water; the soluble glass with low module, there are many kinds of crystal composition and the cohesive force is poor, and when the module number improves, the colloid component increases and the cohesive force rises.

Soluble glass solution can be mixed with water in any proportion. Different amount of water will lead to solutions of different density and viscosity. For the soluble glass solutions with the same module, the higher the density is, the stronger the cohesive force is. If urea is added into soluble glass, its cohesive force can be improved without modifying the viscosity.

Soluble glass also has strong acid corrosion that can resist the majority of inorganic acids, organic acids, and corrosive gases. The silicate gel precipitating during the hardening of soluble glass can block the capillary porosity of the material to prevent water infiltration. Soluble glass has good heat resistance, so it does not dissolve and its strength does not decrease and even increases at a high temperature.

In addition, the soluble glass can burn eyes and skin to a certain extent, so the security protection is needed.

3.4.4 Applications of Soluble Glass

1. Acid-proof Material

Soluble glass can be used as binding material to prepare acid-proof plaster, acid-proof mortar, and acid-proof concrete which are commonly used in anti-acid projects.

2. Heat-resistant Material

Soluble glass has a good heat resistance that can bear a certain high temperature and its strength does not increase. Thus, it can be made into heat-resistant concrete and mortar.

3. Coating

Soluble glass solution can be used to paint building materials or immerging porous materials. It can enhance the density and strength of materials and increase their resistance to weathering when infiltrating into the materials. But the solution can not be used to paint or immerge gypsum products because soluble glass can react with gypsum to generate sodium sulfate crystals which will expand in pores and destroy the gypsum products.

4. Grouting Material

Soluble glass solution and calcium chloride solution are injected into soil alternately, and the two solutions will cause chemical reaction to precipitate silicate gel which can cement or fill the pores of soil and prevent the infiltration of water to increase the density and strength of soil.

5. Water-proof Plugging Material

Soluble glass solution mixed with sand or cement can make setting and hardening occur quickly, for repairing or plugging structures. Moreover, mixed with various alum solutions, soluble glass can be used as water-proof agent for cement mortar or concrete.

Questions

3.1 Try to narrate the characteristics of air hardening binding materials and hydraulic binding materials.

3.2 What are the major chemical components of building gypsum? What are the characteristics? Where is it used?

3.3 Try to narrate the mechanics of setting and hardening of gypsum.

3.4 Why should the lime using on the construction site be aged?

3.5 What are under-burnt lime and over-burnt lime? And their characteristics.

3.6 What is stabilization? Why should lime be stabilized before use?

3.7 Try to explain the reason why gypsum and lime are not water-resistant.

3.8 Why can't magnesia be stirred with water alone in use?

3.9 What are the main characteristics and purposes of soluble glass?

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