Discussion on Factors Affecting the Fluidity of Mortar

Abstract

Building mortar is a kind of material with a large amount of application and a wide area of use in construction. Foreign mortar has achieved multi-function, multi-variety, and serialized modern production of product. Self-leveling mortar is a new material appearing internationally in the early 1980s.

Self-leveling mortar is mainly used for ground surface construction, and after hardening will form the smooth, wear-resistant surface. And it can be pumped in construction, saving labor an construction costs, and improving the efficiency and quality of construction. Compared with the manual plastering in the traditional ground construction, it is an innovation.

However, good fluidity is the basic requirement of self-leveling mortar. Attempts are made in this topic to study from such aspects as the types and dosage of admixtures (such as water-reducing agent, thickener, etc.), the ratio of mortar and the particle size of sand, to test the consistency, degree of extension, compressive and flexural strength, adhesion and other performance indicators of mortar, then analyze and obtain the rules of impacts on the fluidity of mortar.

1. Introduction

1.1 Basic Concepts and Defining Scope of Use

1.1.1 Overview

With the advancement of technology and the development of the construction process, the types of building mortar become more and more abundant and the scope of application becomes wider, which marks that under the condition of achieving the same construction effect, there can be more choices in order to reduce the project cost, shorten the construction period, and become more convenient for construction management. As a kind of building mortar, self-leveling mortar not only has the above characteristics, but also has unparalleled advantages compared to ordinary mortar in the quality of construction. Therefore, in order to better develop and utilize self-leveling mortar, an in-depth and meticulous research on its flow performance has to be made.

I. Basic Concepts

Cement: refers to the powdery hydraulic cementitious material that can bind sand, stone and other appropriate materials and can be hardened in air and water after mixing with water into a plastic paste. It is a generic term for various types of cement. In other words, the cement is a hydraulic cementitious material.

Sand: refers to the rock particles with a particle size less than 5mm formed under natural and artificial conditions. According to the cause of its formation, it can be divided into two kinds: natural sand and artificial sand.

Concrete Admixture: refers to the product that can maintain the working performance of concrete, mortar or cement paste, and can modify concrete, mortar or cement paste, added during the mixing of concrete, mortar or cement paste, etc., before mixing, or in the additional mixing process, with a dosage less than or equal to 5% of cement mass, known as concrete, mortar or cement paste admixture, and concrete admixture for short.

Building Mortar: refers to the building material formed by mixture of cementitious material (cement, gypsum, lime, etc.), fine aggregates, water and admixtures, and used for masonry (coagulating the dispersed bulk materials, bonding as a whole, and transfer the load evenly), plastering (mainly used for decoration or facing bottom), and water proofing (mainly used for masonry of waterproofing layer and plastering of waterproof materials).

Self-Leveling Property: when mortar is cast on a substrate by mixing into paste, it can automatically flow under the action of its own weight and self-expansion stress, and can form a horizontal plane by artificially slight pushing, with self-dense, uniform and stable characteristics itself.

Fluidity: refers to the nature of flow produced by the mortar mixture under its own weight or external force.

II. Defining Scope of Use

As a big family, mortar has different members in the nature, variety and uses. For example, classified according to its cementitious materials, mortar can be divided into cement mortar, lime mortar and mixed mortar; classified by the uses, it can be divided into masonry mortar, plaster (surface) mortar, waterproof mortar, pointing joint mortar and other special mortar; while according to the bulk density, it can be classified into heavy mortar, light mortar and so on. Wherein, self-leveling mortar belongs to special mortar.

Since the fluidity discussed in this thesis is closely linked with self-leveling mortar, herein a brief introduction on the purpose and scope of use is made.

Self-leveling mortar is mainly produced against some quality problems in the ground construction of the existing ordinary mortar. Its scope of use is very clear, like the floors with the features of horizontal plane, not including slanted plane, ramp. It can effectively replace the traditional ground practice, and can also be used to repair the problems easy to appear in the traditional ground construction, and to repair the worn, dusting old ground, making the ground flat, smooth, dense, high strength, and no cracking.

1.2 Background and Significance

1.2.1 Background

The traditional ground material---cement mortar has played a great role in housing construction, met people’s living needs and requirements on the housing use performance in the past, also in line with the characteristics of the times then in the construction technology and process, and provided employment opportunities for a large number of idle labor force. The construction of cement mortar ground is a labor-intensive job. Since its scientific and technological content is not high, in the course of its work, there will inevitably be many shortcomings and problems that are difficult to avoid, which is caused by technological level and construction process. With reform and opening-up, technological progress, and people’s increasing needs of material and cultural life, people have great improvement and requirements on the using standard and comfort level of housing. The traditional cement mortar ground has been difficult to meet. Although people can renovate the housing ground for use in the later period, however, due to the presence of its own quality defects in the flatness, it is difficult to create a good prerequisite for the subsequent projects. As far as the construction unit is concerned, since it is to lower construction costs, shorten the project cycle and achieve better construction quality, the construction of cement mortar ground cannot meet its requirements. Self-leveling material is the reform and development aimed at this problem. Therefore, in order to develop self-leveling mortar, it is necessary to study the fluidity of mortar.

1.2.2 Significance

1. Improve the project quality, and shorten the project cycle. The construction of traditional cement mortar ground often has the following disadvantages:

(1). Labor-intensive, consuming a lot of manpower and material resources;

(2). Long production period, delaying period, resulting in economic losses;

(3). Difficult to guarantee the flatness of dry building floors, bring difficulties for the subsequent construction work;

(4). Dusting, peeling, hollowing, cracking, in need of post-maintenance.

For these reasons, we are required to carry out reforms on the building materials and construction process in ground projects. The biggest characteristic of self-leveling material is self-leveling property. when it is cast on the building floor after mixing into paste, it can be free flow to form a horizontal plane under the action of its own weight and self-expansion stress, not only can overcome the common quality defects difficult to control by the flatness of ordinary cement mortar floors, but also has the following advantages:

(1) stable in quality; (2) high in construction efficiency; (3) convenient for construction management; (4) fully protected in the aspects such as the uniformity, density, strength, flatness and cracks of building floors.

2. Promote the progress of construction technology and boost the modernization of construction industry. The modernization of construction and the modernization of housing construction depend on the progress of construction techniques, while the progress of building techniques in turn is closely related to construction materials. For example, the advances in the housing structure, building functions and construction process depend largely on the building materials. Therefore, the positive development of building materials with better performance is one of the important conditions to promote the progress of construction technology and the only way to boost the modernization of construction industry.

1.2.3 Research Methods and Theoretical Basis of This Topic

I. Research Methods

Since the study on the fluidity of mortar started late, and there are fewer studies, almost no published article, as a new research topic we conducted, it cannot find a theoretical sample to refer to, and only select the appropriate ratio from it to analyze the several parameters and indicators of fluidity, find out the factors related to this characteristic, and to study from its influencing factors. The influencing factors of mortar fluidity the type and amount of cementing materials, water consumption, thickness degree of fine aggregate, grain shape and gradation, stirring time, the dosage and type of admixtures. To this end, we have adopted the experimental method to identify the rule of various factors influencing the fluidity of mortar and propose the ways to improve the fluidity of mortar:

First, choose the representative factor from the influencing factors for experiment;

Second, determine the materials used according to the selected influencing factors for experiment, i.e. material selection.

Third, determine the approximate range of dosage based on the materials themselves and their predetermined roles.

Fourth, conduct the experiment according to the developed experimental plan, and then re-test by increasing or reducing the auxiliary materials according to the test results.

Last, after the basic experiment is finished, according to the analysis of experimental data, summarize the rule of factors influencing the fluidity.

II. Theoretical Basis

As a new research topic, its essence is to carry out the experiment by improving and enhancing the fluidity of ordinary cement mortar, and to achieve the test, analysis and summary of some unique technical parameter indicators by different mixing ratios of ordinary cement mortar, the addition of admixtures, and with the help of auxiliary materials, in order to determine the rule of factors influencing the fluidity of mortar. According to the current general situation, the indicators that can be measured are as follows: (1) intensity; (2) consistency; (3) degree of expansion; (4) adhesion.

Good fluidity of mortar requires a large enough degree of expansion. Especially in the case of determined water-cement ratio, in order to improve its strength, the pore structure of slurry can be improved by adding the mineral powder, making the large holes decreased but the small holes increased to increase its strength and durability, which can be considered as the superposition due to the pozzolanic effect and the water-reducing and densification effects.

Impact on its fluidity can be resolved through a variety of ways.

First, improve by superplasticizers. Superplasticizers are polymeric surfactants, and have strong solid - liquid interface active roles. In the disperse system of cement, they can be adsorbed on the surface of cement particles, and form the negatively charged strong electric field, so that the cement gel will produce dispersion and the fluidity of cement paste will be greatly improved.

Second, improve the performance of mortar by adding an appropriate amount of fly ash. Flay ash is the mixed material in the shape of globular particles with the characteristics of pozzolanic reaction, and can have an effect on the fluidity of cement mortar in both physical and chemical aspects to improve the fluidity of mortar.

Third, mixing with mineral powder can similarly increase the fluidity of cement paste. This is because the mineral powder is the vitreous structure, non-absorbent on the surface, and can fill the gap of cement particles and the structure of flocculation, occupying the water-filling space, releasing the water in the structure of flocculation, and improving the fluidity of slurry.

Since self-leveling mortar has higher requirements on the fluidity, in order to meet the requirements of fluidity, its water-cement ratio has larger parameters used. By adding the expanding agent, it can react with the mineral compositions of cement to produce a crystalline substance, resulting in expansion to compensate for the volume contraction.

The control of bulk density is determined for the fluidity of mortar. In this regard, mineral powder or fly ash can be added for adjustment, adjusting the micro-gradation of self-leveling materials in order to meet the requirements of stability of its internal components, and making the mortar produce automatic leveling.

Add the air-entraining agent or thickener to solve the early bleeding phenomenon. The air-entraining agent mainly makes the cohesiveness of aggregate and cement slurry in the mixture increased, and their dispersion weakened, so enables the mixture to be better in a homogeneous state, and the water used for mixing to stay in the cement slurry for a longer time, thus reducing bleeding property. For the thickener, its purpose is also to improve the stability of mortar, increase the cohesion and water retention, and to reduce the bleeding amount.

In short, by adding different additives and auxiliary materials, the flow properties of mortar can get improved and enhanced to meet our requirements for use. But it is important to note that due to the combined effect of additives and auxiliary materials, there may be some unfavorable factors, which requires in doing experiment we try to avoid some unfavorable factors, and find some products that can make each component play its respective advantages to meet the requirements of experiment.

2. Development of High Fluidity Mortar Materials at Home and Abroad

Domestic and foreign studies on high fluidity mortar materials originated in the beginning of the study on self-leveling mortar. Therefore, in this chapter, regarding the development of high fluidity mortar materials, we will describe from the development of self-leveling materials.

2.1 Development of High Fluidity Mortar Materials at Home

For the research and development of self-leveling mortar materials, China started relatively late too. The first research and development of self-leveling materials in China is the nature of the project by Beijing Graduate School of Wuhan Industrial University (1987), and the specific content is unknown. In 1994, Liaoning Chaoyang Second Construction Corporation and Liaoning Liaoyang Architectural Design Institute researched and developed the self-leveling, soundproof, tile-like floor. In the past two years, Building Materials Science Research Institute in Beijing has developed the single-component self-leveling floor materials suitable to the condition of China, by large area applications in projects, with good results.

2.2 Development of High Fluidity Mortar Materials Abroad

The self-leveling materials abroad is divided into two categories: gypsum-based self-leveling materials and cement-based self-leveling materials. The products are bagged for sale (30Kg/bag). Simply add water on site according to the provisions for mixing during use, but for some products no fine aggregate is added, so it needs to be added then on site.

The development of self-leveling materials is earlier in Japan. From 1972 to 1973, the basic research on gypsum-based and cement-based self-leveling materials was first conducted by Residential Public Corporation of Japan. In 1976, the construction test was carried out on the gypsum self-leveling materials with the a-hemihydrate gypsum as the base material. By 1977 there had been goods for sale. Currently, there have been 11 brands of gypsum leveling products from 7 companies in Japan, selected and used for the ground of commercial buildings, schools, and collective residential buildings, etc. In West Germany, Paeiro Company used Ⅱ-anhydrite and Qiloni Company used a-gypsum to produce the self-leveling materials with the intensity of 20-30MPa, and the laying thickness of 10mm. The gypsum cement companies in the U.S. once adopted the mixture of a- and β- gypsum. The self-leveling materials pumped after adding aggregates on site have also been widely applied, its production up to 2000m^2/day and the compressive strength of the layered floor more than 21MPa.

For the gypsum self-leveling material, since gypsum has poor water resistance, is neutral or acidic, and has the danger of corrosion on iron pieces, its scope of use is restricted. Thus, the research and development of cement self-leveling materials have attracted international attention. Japan formally sold goods in 1982, and currently there have been 7-9 brands of cement self-leveling materials produced by 7 companies. Some European and American countries have also been launching cement self-leveling materials. For example, the cement self-leveling materials sold by Pyletwick Company of Finland can be thin layering of lmm and not produce shrinkage cracks.

3. Relationship between Composition of Mortar and Its Mechanical Properties

Mortar, also known as building mortar, is the building material used for masonry, plastering and made by mixing cementitious materials, fine aggregates and admixtures. According to the cementitious material it can be divided into cement mortar, lime mortar and mixed mortar, and the research object of this topic is mainly the cement mortar with cement as the cementitious material.

3.1 Composition Materials and Properties of Mortar

3.1.1 Composition Materials

1. For cement mortar, its cementitious material is cement, and the commonly used includes ordinary portland cement, slag portland cement, pozzolana portland cement, fly ash portland cement, masonry cement, and the cement with no or little clinker. The cement grade used should be 4-5 times that of the mortar strength, and generally cement of 27.5#~42.5# is used.

2. For the fine aggregate, generally use the sand up to the JGJ52 - 92 standard (*Content Limits of Ordinary Harmful Substances l%*). For its mud content, perform according to the strength grade of mortar. If the strength grade is greater than or equal to that of M5, the mud content and the content of clay lump should be less than or equal to 5%. If the strength grade of mortar is not less than that of M5, the mud content and the content of clay lump will be less than or equal to 10%. And impurities

should not be mixed in sand.

The mica, sulfide, sulfate, chloride and organic matter in sand are harmful substances, and their contents should meet the requirements in the following table.

Table 3.1 Content Limits of Harmful Substances in Sand (%)

Items	High-Class Products	First-Class Products	Qualified Products
Mica	1	2	2
Sulfide and Sulfate (counted by SO_3) ＜	0.5	1	1
Organic Matter	Qualified	Qualified	Qualified
Chloride (counted by NaCL)	0.03	0.1	——

3. Water should be pure water, fresh water, or drinking water, and the untested sewage should not be used.

3.1.2 Material Properties

Since cement has a lot of types, it is impossible to analyze in detail its physical and chemical properties here. Therefore, only ordinary the 42.5 # portland cement used in this topic will be explained.

I. Ordinary Portland Cement and Its Composition

Ordinary portland cement contains four kinds of main mineral composition, namely, tricalcium silicate, β-dicalcium silicate, tricalcium aluminate and tetra-calcium aluminoferrite, of which tetra-calcium aluminoferrite often exists in various forms of solid solution. The following table shows the molecular formula of various minerals.

Table 3.2 Main Mineral Composition of Ordinary Portland Cement

Mineral Composition	Molecular Formula	Abbreviated Formula
Tricalcium Silicate	$3Ca\cdot SiO_2(CaSiO_4)$	C_3S
β-Dicalcium Silicate	$2CaO\cdot SiO_2(CaSiO_4)$	C_2S
Tricalcium Aluminate	$3CaO\cdot Al_2O_3(Ca_3AlO_3)$	C_3A

Tetra-Calcium Aluminoferrite	$4CaO \cdot Al_2O \cdot Fe_2O_3$	C_4AF

II. Hydration Reaction of Ordinary Portland Cement

The four main minerals in cement are anhydrous compounds. When they meet with water, the hydration reaction will all occur. The strength increase in hydration of various mineral composition is all different. The characteristics shown by the hydration of four kinds of cement clinker minerals are briefly expressed in the following table.

Table 3.3 Hydration Characteristics of Cement Clinker Minerals

Items	C_3S	C_2S	C_3A	C_4AF
Setting and Hardening Speed	Fast	Slow	Fastest	Faster
28d Hydration Heat Release	Much	Little	Most	Medium
Strength	High	High strength earlier, low strength later	Low	Low

III. Main Physical and Mechanical Properties of Ordinary Portland Cement

Not only portland cement must meet the national standards for fineness, consistency, setting time and stability, strength, and other quality indicators during use, but also are there some other properties affecting its use, such as the hydration heat, bleeding and water retention, alkali-aggregate reaction, and ways to improve durability. Now a brief introduction of several properties related to the fluidity will be made.

(1) Fineness

The fineness of cement means that the thickness degree of cement particles is closely related to a series of properties such as setting time, strength, dry shrinkage and heat release rate of hydration. Generally, the finer the particles are, the larger the surface area in contact with water will be, and the faster the hydration reaction and the early strength development will be. But if the particles are too fine, shrinkage will be greater in setting and hardening, and it is easy to produce cracks.

(2) Consistency

The consistency is actually the required amount of water for cement slurry to reach a certain degree of fluidity, and one of the important properties of cement.

The factors affecting the consistency of cement include: the mineral composition of cement clinker, the nature and addition amount of mixed materials, admixtures, and the grinding fineness of cement.

(3) Setting Time

The process of cement beginning from mixing with water to the loss of fluidity, that is, the process developed from a liquid state to a denser solid state is called the setting process of cement, and the time required for this process is called the setting time. In order to better reflect the setting time of cement and facilitate the construction, the setting time is in turn divided into the initial setting time and final setting time. The initial setting time refers to the time from cement mixing with water to cement slurry beginning to lose plasticity; the final setting time refers to the time from cement mixing with water to cement slurry completely losing plasticity and beginning to produce strength.

(4) Strength

The strength of cement is an important indicator for the evaluation of cement quality, and a basis for the division of cement grades. The strength of cement refers to the capacity of cement mortar hardened specimen to withstand the external force, expressed in MPa (megapascals). It is one of the important physical and mechanical properties of cement. According to the different forms of force, the strength of cement is usually divided into three kinds: compressive strength, flexural strength and tensile strength.

There are many factors affecting the strength of cement, such as the mineral composition of clinker, the content of free calcium oxide and other trace chemical composition, the types and amount of mixed materials added in the cement, the addition amount of gypsum, the grinding fineness of cement, the curing conditions of specimen, and the test method of strength.

(5) Bleeding and Water Retention

Bleeding, also known as the water-separating property, refers to the performance to secrete part of mixing water from cement slurry.

Water retention refers to the capability for the material to maintain moisture, and the performance opposite to bleeding. With good water retention, during standing of paste, moisture will not be secreted, but with absorbent template, vacuum oscillation, or vacuum suction, moisture can be released.

Improving water retention can be achieved by means of reducing bleeding. Improving the grinding fineness of cement and accelerating the formation of cohesion structure can reduce bleeding. Adding pozzolanic mixed materials in the cement such as diatomaceous earth, bentonite, and microcrystalline fillers such as limestone, dolomite can increase its required amount of water but reduce bleeding.

3.2 Analysis of Auxiliary Material Properties

Good fluidity of mortar is modified by adding admixtures and auxiliary materials into ordinary mortar. In order to achieve this property, the choice of admixtures and auxiliary materials is quite important. The main technical key is to solve the contradiction between too high fluidity and stability, the contradiction between early strength and slow setting and the contradiction between bleeding and segregation. To this end, in reference to domestic and international data studies, the choice of the following materials is specially made: water-reducing agents, fly ash, thickeners, and adhesive powder.

3.2.1 Water-Reducing Agent

The water-reducing agent is to reduce the water amount of given concrete (or mortar, paste) under the condition of not affecting the workability of concrete (or the fluidity of mortar, paste); or to increase the workability of concrete (or mortar, paste) under the condition of not changing the water amount. While keeping the concrete mixture with the same fluidity and the hardened concrete with similar strength, adding water-reducing agents can decrease the amount of cement. These three are connected with each other in nature.

Internationally the admixtures with the above properties are often referred to as "water-reducing agents", sometimes also called "plasticizing agents”. In face of the water-reducing agents with higher water-reducing capacity they are often referred to as superplasticizers. In China, they are generally referred to as water-reducing agents, and those with better performance are called “superplasticizers”. The molecule of water-reducing agent consists of the polar functional group part that can be adsorbed on the surface of of cement particles , and the nonpolar part that enables the surface of mineral composition to show hydrophobic. In general, its molecule is divided into two parts: polar group and nonpolar group.

I. Structure and Performance of Polar Group

The polar group mainly determines the affinity of water-reducing agent on the mineral composition of cement particles, which is shown in the effects on the chemical properties (including chemical adsorption capacity and chemical reaction behavior, etc.) and physical properties (including the degree of dissociation, solubility, polarity, and physical adsorption performance, etc.) of the entire admixture molecules or ions. Since the cross-sectional area of polar group is usually larger than that of nonpolar group, the entire molecules of water-reducing agent are determined by it.

II. Structure and Performance of Nonpolar Group

The structure of nonpolar group is varied. With the differences in the types of polar group and in the uses of admixtures, the nonpolar group is required to have a specific structure and size. The impacts of non-polar group on the properties of admixtures mainly include the following aspects:

1. When the admixture molecules (or ions) are oriented adsorbed onto the surface of cement mineral composition, the nonpolar group is outwards, forming a hydrophobic film layer, so the structural features of the nonpolar group directly affects its hydrophobicity.

2. When the admixture is adsorbed onto the surface of cement particles, nonpolar groups will interact. When the admixture is adsorbed onto the surface of particles, it should not only overcome the solid affinity of polar group, but also overcome the force that prevents nonpolar groups separating from each other. And this force is directly related to the structure of nonpolar group. Therefore, the structure of nonpolar group also determines its solid affinity for cement.

3. Nonpolar groups can also have an impact on the adsorption capacity of polar groups by means of inductive effect, conjugative effect, and spatial effect.

In addition to the above effects, the nonpolar group mainly determines the hydrophobic properties of admixtures, and it play a decisive role in the solubility and surface activity of admixtures.

III. Relationship in the Structure Between Polar Group and Non-polar group of Molecule

1. What structure and size of nonpolar groups are more appropriate to be combined with the polar groups of different structural performance? Due to the effects of chemical composition and crystalline characteristics of various cement

mineral components, various kinds of polar groups have great differences in requirements for nonpolar groups. For silicates, since most of the cleavage plane is the ionic chain, therefore, adapted to it are fatty acids, sulfonic acids and fatty amines with longer hydrocarbon chain.

2. The mode of action between admixtures and cement minerals depends on the characteristics of admixtures and composition of cement minerals. The mineral mainly by physical adsorption requires the nonpolar groups of larger molecular weight, while for that depending on the intermolecular force as an auxiliary means to make admixtures fixed on the mineral surface of cement, it also requires quite large nonpolar groups; for the substance by the chemical adsorption of covalent bonds to produce fixing, the role is stronger and the polarity is low, so there is no need for too large nonpolar groups.

IV. Relative Number And Location of Nonpolar and Polar Groups

When there are two or more polar groups in one molecule, if these plurality of polar groups consist of the complexing group, then the solid affinity of polar group will get enhanced due to complexation; if not combined into the complexing groups, then they can produce mutual influence.

If there are a number of nonpolar groups in a molecule, then there will be different effects depending on whether these polar groups are on the same carbon atom, whether branching is produced, and whether the heterogeneous is formed.

The position of polar group in the molecule also has an impact on the performance of water-reducing agent. Generally, when the polar group is located at one end of molecule, the performance is better.

3.2.2 Fly Ash

Fly ash, also known as flyash, is the dust collected from the chimney of coal-fired thermal power station. Generally speaking, fly ash is finer than cement, and contains a large amount of spherical glass beads.

The performance of fly ash changes greatly, and is related to many factors, such as the variety and quality of coal, coal fineness, ignition point, oxidizing conditions, pretreatment and desulfurization before combustion, as well as collection and storage methods of fly ash.

(1). Chemical Constituents and Mineral Composition of Fly Ash

The chemical constituents of fly ash are determined by the constituents of raw coal and combustion conditions. According to the data from 40 large power plants in our country, the range of variation in the chemical constituents of fly ash is shown in the table.

Table 3.4 Chemical Constituents of Fly Ash (Mass %)

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_2	Loss on Ignition
Range of Variation	20~62	10~40	3~19	1~45	0.2~5	0.02~4	0.6~51

The constituents of coal in part of the thermal power plants are SiO_2 40%~50%; Al_2O_3 20%~35%; Fe_2O_3 5%~10%; CaO 2%~5%; and loss on ignition 3%~5%, of which SiO_2 and Al_2O_3 are the main active ingredients in fly ash.

Regarding the mineral composition of fly ash, according to the researches at home and abroad, it is agreed that they are mainly: vitreous body, mullite, quartz and a small amount of other minerals, seen in the table below:

Table 3.5 Mineral Composition of Fly Ash

Composition	Vitreous Body	Mullite	Quartz
Range (%)	69.4~84.4	7.8~18.2	5.4~11.5
Average (%)	77.6	12.2	8.5

In addition, fly ash contains calcite, anorthite, β-C_2S, hematite, and a smaller amount of sulfates and phosphate minerals.

(2) Physical Properties of Fly Ash

The physical properties of fly ash is shown in Table 3.10. The specific surface area of fly ash is determined according to the determination method of the specific surface area of GB287-63 cement.

Table 3.6 Physical Properties of Fly Ash

Fly Ash		Density (g/cm^2)	45μ Sieve Residue（%）	25μ	10μ	Specific Surface Area（cm^2/g）	Glass Bead Content（%）
Original Ash		2.11	35.2	79.0	——	——	75
Graded Ash	10μ	2.83	——	——	1.4	7850	90
	25μ	2.43	——	1.0	22.6	5690	85~90
	45μ	2.31	5.7	41	——	3290	80
Ⅱ Grade Ash		2.15	19.1	70	——	4200	35

3.2.3 Thickeners

I. Overview

The admixtures that can increase the consistency of concrete, mortar, cement paste and other mixture, and has good water retention, are known as thickeners, also called water-retaining agents. For the high fluidity concrete (such as pumping concrete, self-leveling concrete, underwater non-dispersible concrete, etc.) and mortar added with water-reducing admixtures, although the amount of water used in concrete and mortar is small, concrete and mortar may also be segregated and poor in cohesion, resulting in layering after casting molding of concrete or mortar, and leading to uneven quality of concrete or mortar. If a small amount of thickener is added into these high fluidity concrete or self-leveling mortar, then the cohesion of concrete and mortar is good, without segregation or bleeding, thus ensuring the construction quality of concrete and mortar.

II. Types and Action Mechanism of Thickeners

Thickeners are mostly aqueous polymer compounds, such as polyvinyl alcohol, cellulose ethers and their derivatives, carboxymethyl cellulose, hydroxyethyl cellulose, polyacrylic acid and polycarboxylate methacrylic acid, all of which can increase the the viscosity of water. The water-soluble viscosity of these substances depends on their concentration. For example, the aqueous solution viscosity of 1% carboxymethyl cellulose is 15 ~ 70Pa.s, and that of 4% is 25~150 Pa.s. But for the polymer electrolytes, the viscosity of the aqueous solution depends on their molecular form and PH value.

Therefore, the aqueous solution polymer compound can be used to increase the viscosity characteristics of water, act as the active ingredient of new superplasticizer, efficient air-entraining water-reducing agent for the configuration of flow concrete, pumping concrete, self-leveling mortar, high performance concrete, etc., used to improve the rheological properties of these concrete, reduce the loss of fluidity, reduce bleeding and segregation, improve the cohesion and water retention of concrete mixture, give new process performance and to improve the working performance. In general, when the aqueous solution polymer compound is used as the thickener of concrete or mortar, its addition amount is smaller. Too high addition amount will lead to too viscous mixture and decrease in fluidity, while making the setting time of concrete, mortar become longer.

Cellulose, as a kind of thickener, is used in this experiment, and specially introduced hereby. The relative molecular mass of cellulose ranges from several thousand to several tens of thousand. Mainly for increasing the viscosity, it is added in the powder form into concrete or mortar, and during stirring with water, it gets dissolved and becomes a viscous liquid. The viscosity of solution will increase with the increase in the concentration added. In the concentration, it enables the viscosity of water greatly increased (10^4 times).

Thickening Mechanism of Cellulose:

When long chain molecules are dissolved in water, the oxygen atoms and water molecules on their hydroxyl groups and ether bonds will form hydrogen bonds and associate, making water lose fluidity, so the viscosity of solution will be significantly increased. When added into cement slurry, it will form water retention slurry. It has a stabilizing effect on the dispersed cement slurry (due to the addition of superplasticizer at the same time), while increasing the cohesiveness.

3.3 Relationship Between Material Composition of Mortar and Its Mechanical Properties

The basic composition materials of ordinary mortar are cement, water and sand. With the raise of cement grade and the increase in the amount of cement, the strength of mortar will be increased accordingly. The larger the water-cement ratio is, the greater the shrinkage of mortar will be, easy to produce shrinkage cracks and strength decrease, which shall not be the focus of discussion hereby. Only the effects of admixtures and auxiliary materials on the mechanical properties of mortar are briefly introduced so that we can have a simple understanding of the use and dosage of admixture and auxiliary materials.

3.3.1 Water-Reducing Agent

The water-reducing agent is generally a surfactant, and mostly the amount is relatively large, also with the role of polyelectrolyte. When added into and mixed with the cement slurry, it can play a series of performance. Its mechanism is summarized as follows:

1. Water-reducing agent is adsorbed by cement particles:

Cement belongs to ionic compounds and has a strong affinity for water, so when water contains the molecules of water-reducing agent, cement will make these molecules or ions adsorbed on its surface. However, due to the irregularity of cement particles, the adsorption activity on the edge, angle and edged face is greater, while on the flat plate, the relative adsorption is less, showing uneven adsorption, which has created the conditions for cement particles to take the aggregative state favorable to movement.

2. Water-reducing agent changes the charge of cement particles:

After the molecules (or ions) of water-reducing agent are adsorbed on the surface of cement particles tables, changes will take place in the charge of fine particles of cement. Generally the water-reducing agent is mostly anionic, and has a negative charge itself. For all the above reasons, changes will take place in the ξ potential of cement particles, and the greater the concentration of water-reducing agent is, the lower the ξ potential will be.

3. Water-reducing agent makes cement particles get dispersed:

The water-reducing agent itself is the macromolecule containing a plurality of groups, a part containing polar groups and adsorbed by cement particles, while the other part of groups not adsorbed and towards the water, making cement particles have a larger, thicker solvent layer of molecules. These molecules of water-reducing agent lie under the surface of cement particles, it is very difficult to take the upright adsorption onto the surface of cement particles like ordinary surfactants with multiple molecules.

Due to the above two effects, together with the molecules adsorbed by the molecule of water-reducing agent itself, a similar kind of film layer has a certain strength; the molecules of water-reducing agent tend to have complexing capability, equivalent to the production of adsorption. For the above reasons, the cement particles with the addition of water-reducing agent have had better sedimentation and polymerization stability so that the cement particles get better dispersed.

4. Air-Entraining Effect of Water-Reducing Agent

Some water-reducing agent can often significantly reduce the surface tension of aqueous solution. Therefore, having a certain air-entraining property can introduce air bubbles, making the fluidity of concrete mixture increased.

In short, after adding water-reducing agent and appropriately reducing the amount of water for mixing, the impact on the structure of cement stone can be summarized as follows: improving its strength, compactness and durability; accelerating the early hydration rate of cement, making the early strength, middle and late hydration rate of cement slow down, slowing the transformation process of cement hydrates from gels to crystals, changing the pore diameter of cement stone, making the pore diameter become small.

3.3.2 Fly Ash

I. Effects of Fly Ash on the Fluidity of Cement Mortar

Fly ash is a mixed material of spherical particle with the characteristics of pozzolanic reaction, and can have an effect on the fluidity of cement mortar from both physical and chemical aspects. From the physical aspect: the fly ash of spherical particle can play a ball bearing lubricating role in the flow of mortar. From the chemical aspect: compared with cement, fly ash has a lower early hydration reaction rate, and less adsorption of superplasticizers, and enables superplasticizers to fully improve the fluidity of mortar.

The effects of fly ash on the fluidity of cement mortar are shown in Figure 3.1 and 3.2. As can be seen from the figure, fly ash is indeed able to improve the fluidity of cement mortar. Despite the differences in the type of cement and the mixing ratio of mortar, the fluidity of mortar will all be improved with the increase of fly ash content.

However, there seems to be a certain limit for this effect of fly ash improving the fluidity of mortar. According to the experimental results, when the mass fraction of fly ash added is more than 10%, with the increase of fly ash content, the increase in the fluidity of mortar will become small.

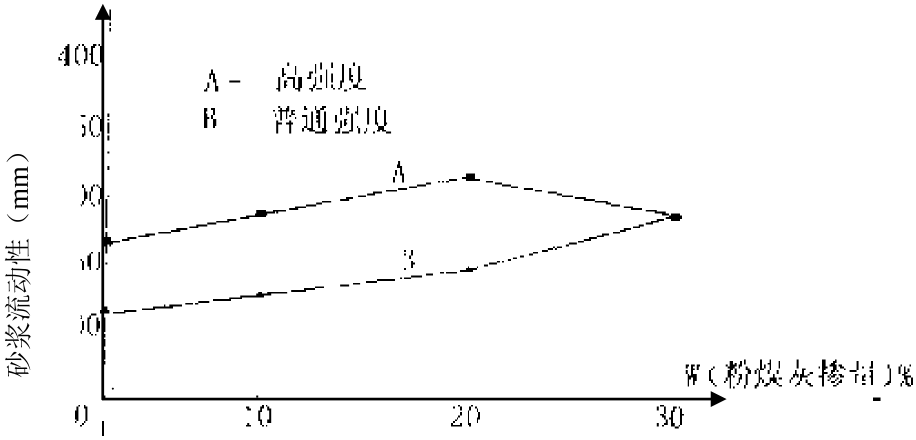

Figure 3.1 Effects of Fly Ash on the Fluidity of Type I Portland Cement Mortar

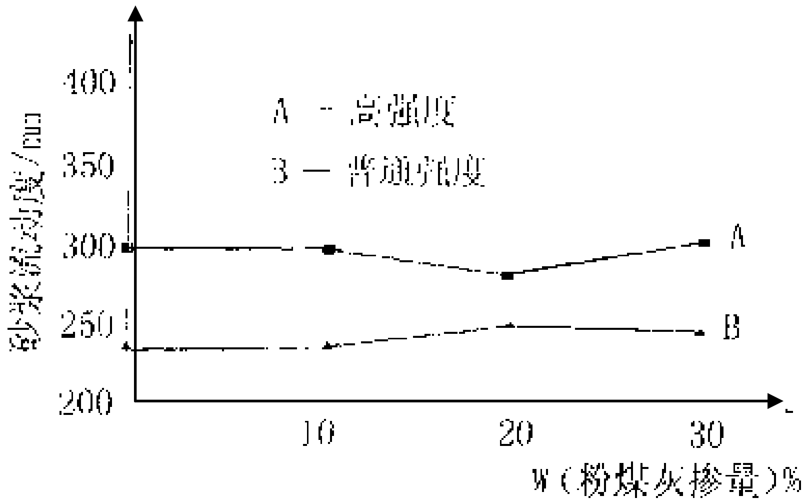

Figure 3.2 Effects of Fly Ash on the Fluidity of Ordinary Portland Cement Mortar

II. Effect of Fly Ash on the Compressive Strength of Hardened Mortar

The effect of fly ash on the compressive strength of hardened cement paste is as shown below:

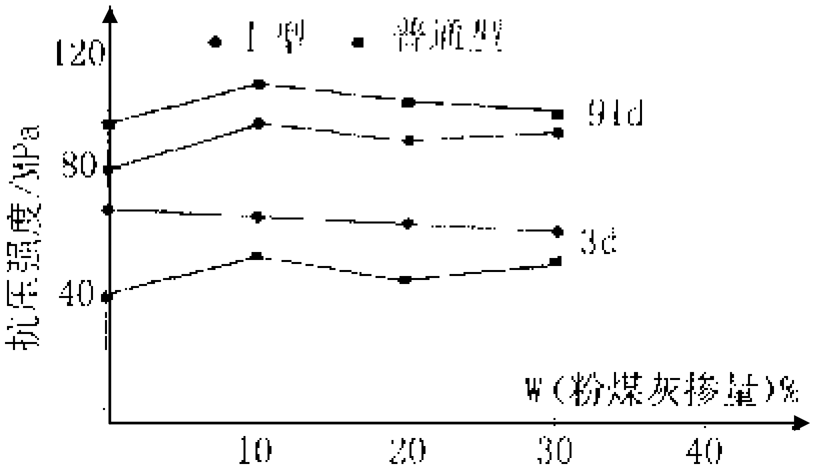

Figure 3.3 Effect of Fly Ash on the Compressive Strength of Mortar

As can be seen from the figure, the effect of fly ash on the compressive strength of cement mortar is related to the fly ash content. In the ordinary portland cement mortar, when the mass fraction of fly ash content is less than 10%, it can significantly improve the early strength; when the mass fraction of fly ash content is 0%-10%, the growth rate of early strength gradually slows down. In the type I portland cement mortar, when the mass fraction of fly ash content is less than 10%, it almost has no effect on the early strength; when the mass fraction of fly ash content is 10%-30%, the early strength of mortar will gradually be reduced with the increase of fly ash content. For the late strength of mortar, whether ordinary portland cement or type I portland cement, when the mass fraction of fly ash content is less than 10%, the growth rate of late strength will be increased with the increase of fly ash content; when the mass fraction of fly ash content is 10%-30%, the growth rate of late strength will gradually be decreased with the increase of fly ash content.

Since fly ash has good micro-aggregate effect and pozzolanic effect, when the fly ash content is smaller, in the early hydration of cement, the finely ground fly ash is filled between cement large particles as well as cement and sand, optimizing the particle size distribution, thereby increasing the compactness degree of the cement stone and making the intensity increased. Meanwhile, fly ash has good pozzolanic activity. When the mass fraction of fly ash content is less than 30%, after hydration it is able to quickly react with $Ca(OH)_2$ produced by hydration of clinker mineral to form the hydrated calcium silicate gel and hydrated calcium aluminate, making the structure of cement stone more compact and thus the late strength increased.