Experimental Study on the Fluidity of Mortar

In determining the parameter indexes to be tested in this experiment, workability, and the choice of additives and auxiliary materials, through the analysis of some existing products at home and abroad and the study on the properties of admixtures and auxiliary materials, together with some of the requirements in the use that mortar must meet, the following technical parameter indexes are specially drawn up as the indexes for us to asses:

1. Fluidity (degree of extension)
2. Consistency
3. Strength (flexural strength, compressive strength, tensile strength)

Of these indexes, the fluidity (degree of extension) is the key indicator for us to detect.

In the selection of admixtures and auxiliary materials, it is mainly determined based on the material properties and in practice the impact on the technical parameter indexes of mortar to be tested.

The following materials are the preferred auxiliary materials of the experiment:

Water-reducing agents: mainly separating the structure not suitable for the flow of slurry in the slurry particles, for the dispersing effect and to achieve the purpose of reducing water and increasing the fluidity.

Fly ash: using its properties in physical and chemical aspects, in order to achieve the purpose of increasing fluidity and strength.

Thickeners: used to improve the stability of mortar, and increase the cohesion and water retention.

Adhesive: the main ingredient is vinyl acetate, used to enhance the cohesiveness of mortar and flexibility.

4.1 Experimental Preparation

Given the nature of test and the arrangement of staff, it is required to make full preparations before the test, so as to avoid affecting the experiment due to lack of materials.

Experimental Location: Area B Laboratory Building, Chongqing University

Experimental Program:

Based on the factors affecting the fluidity of mortar: the type and amount of cementing materials, the amount of water added, the thickness degree of fine aggregate, the grain shape and gradation, stirring time, and the type and content of admixtures, we choose the representative factors from the influencing factors for experiment, i.e., the mixing ratio of mortar, gradation, the type and dosage of water-reducing agent, thickener and adhesive. Given the limited laboratory conditions, we have only tested the consistency, degree of expansion, and the early strength of mortar, to assess the impact of the aforesaid factors on the fluidity of mortar from the three aspects.

Preparing Plan for Experimental Materials:

According to the information currently available, the generally required materials are planned as follows:

1. Ordinary Portland cement (42.5 # cement)
2. Sand
3. Superplasticizer
4. Fly ash
5. Thickener
6. Adhesive

The main laboratory instruments and equipment:

1. Pressure testing machine

2. Flexural testing machine

3. Tensile testing machine

4. Mortar mixer

5. Mortar Consistency Meter

6. Jumping table (steel rule and test cone attached)

7. Cement mortar vibration compaction equipment

8. Weighing equipment (tray balance, measuring cups, measuring cylinders)

9. Mortar test mold

4.2 Experimental Process and Results

In this experiment, the following designed kinds of mixing ratio are used for experiment, seen in the following table.

Table 4.1 Mortar Mixing Ratio Design

Type of Mortar	Water-Cement Ratio W/C	Sand/Cement S/C	Mass Fraction of Superplasticizer Dosage (%)
Ultrahigh Strength	0.38	1.0	1.0
High Strength	0.45	1.8	0.8
Ordinary Strength	0.75	2.5	0.5
Low Strength	0.65	2.0	0

During the experiment, the appropriate ratio can be selected from the above table as a reference according to the specific needs.

4.2.1 Effects of Mortar Mixing Ratio on the Fluidity of Mortar

In the experiment, the above four kinds of ratio have been used for experiment, and the water-reducing agent used is the naphthalene superplasticizer, as well as the ultra-fine sand with the maximum particle size of 0.60mm. The experimental test results are seen in the table below:

Table 4.2 Data Records of Effects of Mortar Mixing Ratio on the Fluidity of Mortar

Types of Mortar	Consistency (mm)	Degree of Expansion (mm)	Flexural Strength (MPa)		Compressive Strength (MPa)	
			7d	28d	7d	28d
Ultrahigh Strength	111	112.5	10.7	11.5	47.6	83.7
High Strength	99	96	10.5	11.2	55.3	93.1
Ordinary Strength	101	104	5.6	7.1	21.6	46.1
Low Strength	104	107	6.1	8.6	25.9	60.9

The graphics made are as follows:

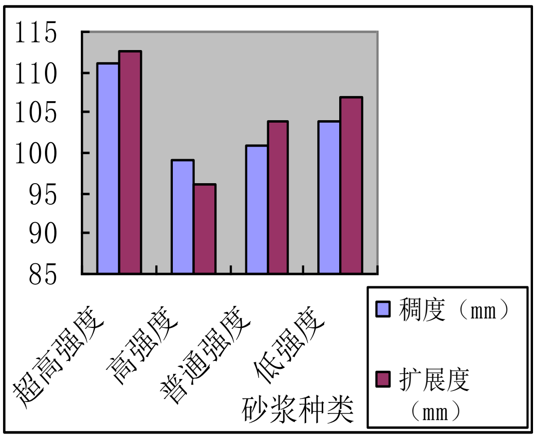


Figure 4.1 Effects of Mortar Mixing Ratio on the Consistency and Degree of Expansion

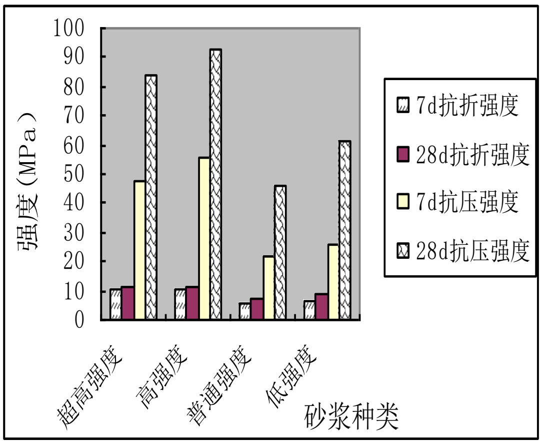


Figure 4.2 Effects of Mortar Mixing Ratio on the Strength of Mortar

As can be seen from the data and graphics of experiment, in the case of the same sand content, the strength is the highest under the design situation of high strength mixing ratio, followed by the that of ultra high strength, while that of low intensity is higher than ordinary strength. The abnormal situation has appeared. This is because in the case of the same sand content, the amount of cement used for ultra high strength is the most, followed by high strength, and ordinary strength is the least. But the difference in the amount of water added leads to the irregularity of strength. However, it can also obtained from the data and analysis above that as the water-cement ratio increases, in the case of the same cement amount, the amount of water used will increase; the volume of solid component will reduce; and the viscosity of mortar will decrease. Therefore, the consistency and the degree of expansion will appear the above phenomenon, and the intensity will also show a corresponding change.

The cement and sand grains in the mortar, by the point contact, produce cohesion. The cohesion size depends on the particle shape, size and the number of solids. As the contact points increase, the role of geometric constraint get strengthened, and the static friction force and the cohesive force are both increased. With the increase in the amount of water used, the ion concentration in the electric double layer structure gets reduced, resulting in the decrease of counter ions in the adsorption layer, but the increase of excess counter ions in the diffusion layer. As a result, the thickness of adsorption layer is increased and the potential value also increases. Therefore, the electric repulsive force is increased, leading to the rapid decrease of cohesive force with the increase in the amount of water used. Thus, as the water-cement ratio is increased, the yield stress of mortar will be reduced.

4.2.2 Effects of the Maximum Particle Size of Sand on the Fluidity of Mortar

In this experiment, the mixing ratio of ultra-high-strength mortar is used for experiment, and the water-reducing agent is still naphthalene superplasticizer. For sand, the following four kinds are used: 0.30mm, 0.60mm, 1.18mm, 2.36mm (All are the maximum particle size). The experimental data after processing are recorded as follows:

Table 4.3 Data Records of the Effects of Sand Maximum Particle Size on the Mortar Performance

Maximum Particle Size of Mortar (mm)	Consistency (mm)	Degree of Expansion (mm)	Flexural Strength (MPa）		Compressive Strength （MPa）	
			7d	28d	7d	28d
0.30	110	114.5	9.5	12.3	42.1	79.2
0.60	101	112.5	10.6	11.5	47.6	83.7
1.18	95	105.5	8.8	9.4	41.3	81.9
2.36	93	101.5	8.3	8.9	38.5	78.7

The trend graphs made are as follows:

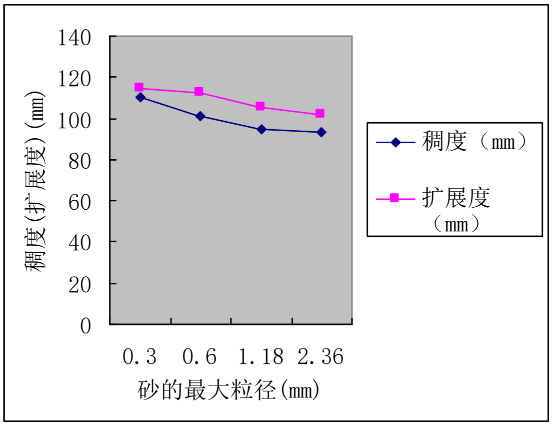


Figure 4.3 Effects of Sand Maximum Particle Size on the Consistency and Degree of Expansion

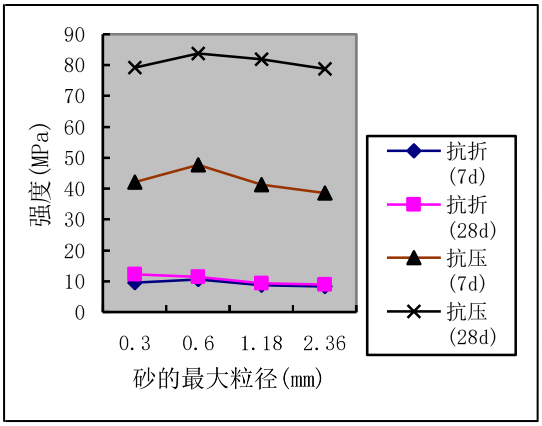


Figure 4.4 Effects of Sand Maximum Particle Size on the Strength of Mortar

As can be seen from the graphs and data above, the smaller the particle size of sand is, the greater the consistency and degree of expansion will be; while the effect of strength will show an irregular phenomenon, which may be caused by the presence of errors in the experiment. In short, according to the theory, whether for the early strength or the late strength, both are decreased with the increase in the particle size of sand.

As can be known from the data, the fineness modulus of ultra fine sand is between 0.75 to 1.5. For the ultra fine sand, most of the particles are concentrated in (0.160-0.315), accounting for about 64%; the (0.080-0.160)mm particles account for about 21%, fine and small particles. The specific surface area of ultra-fine sand is 90-2100 cm^2/g, twice larger than that of coarse sand. The porosity is greater, about 43%-55%, 10%-15% larger than that of medium, coarse sand.

The effects of sand on the plastic viscosity and yield stress of mortar are manifested in the surface features and particle size distribution of sand grains. If the surface is rough and there are multiple edge angles, when the sand grains are in contact, the frictional resistance will increase and the rheological parameters will also increase; for small and fine particles, the specific surface area is large, and the amount of cement slurry used for lubricating the mortar surface and filling the voids will be increased, approximately with $Q = Ft + \delta$ to represent the amount of cement paste in the mortar. In the formula, Q is the total amount of cement slurry; t for the thickness of lubricating film; F is the specific surface area of sand; δ is the amount of cement slurry required for filling the voids of mortar. If the total amount of cement slurry is certain, reducing the specific surface area and the porosity of sand, the thickness of lubricating film will correspondingly be increased. The decrease in the probability of contact with sand grains can increase the fluidity of mortar.

4.2.3 Effects of Superplasticizer Type and Dosage on the Fluidity of Mortar

In this experiment, the ordinary strength mixing ratios is used for experiment. The fine aggregate is the ultra-fine sand with the maximum particle size of 0.60 mm. The comparative experiment on the following four kinds of superplasticizers is conducted. The test results and trend graphs are as follows:

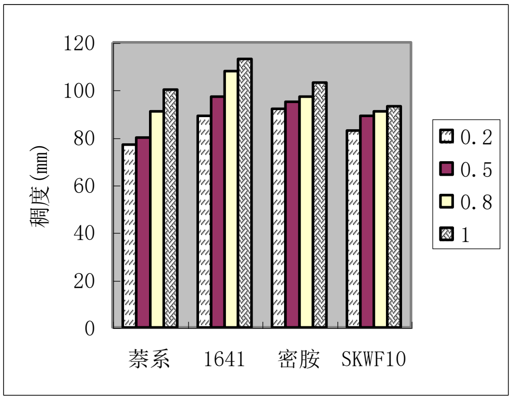
Table 4.3 Consistency of Different Superplasticizer Dosages (mm)

Types of Superplasticizer / Consistency(mm) / Dosage （%）	0.2	0.5	0.8	1.0
Naphthalene	77	80	91	100
1641	89	97	108	113
Melamine	92	95	97	103
SKWF10	83	89	91	93

Table 4.4 Degree of Expansion of Different Superplasticizer Dosages (mm)

Types of Superplasticizer / Degree of Expansion(mm) / Dosage（%）	0.2	0.5	0.8	1.0
Naphthalene	22.8	23.6	26.8	28.9
1641	28.3	29.4	30.5	31.0
Melamine	22.8	24.0	24.7	26.5
SKWF10	23.4	24.1	24.7	26.5

The trend graphs are as follows:



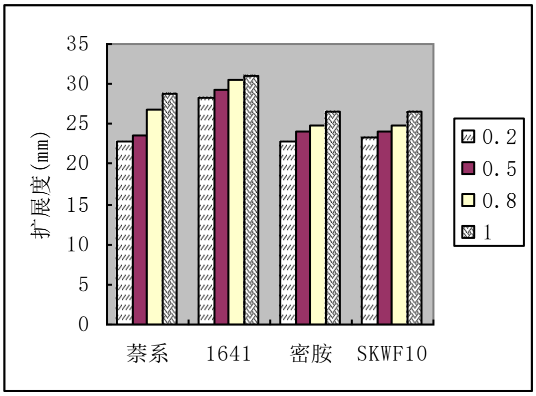


Figure 4.5 Effects of Superplasticizer Types and Dosages on the Consistency of Mortar

Figure 4.6 Effects of Superplasticizer Types and Dosages on the Degree of Expansion of Mortar

Table 4.5 3d Flexural Strength of Mortar Under Different Superplasticizer Dosages (MPa)

Dosage（%） Strength（MPa） Types of Superplasticizer	0.2	0.5	0.8	1.0
Naphthalene	3.8	3.6	3.4	3.1
1641	3.4	3.1	2.3	1.6
Melamine	4.0	3.8	3.6	3.3
SKWF10	4.7	4.3	3.4	3.2

Table 4.6 3d Compressive Strength of Mortar Under Different Superplasticizer Dosages (MPa)

Dosage（%） Strength（MPa） Types of Superplasticizer	0.2	0.5	0.8	1.0
Naphthalene	19.2	18.6	15.8	14.8
1641	16.8	15.8	13.4	10.0

Melamine	18.7	17.4	12.6	11.9
SKWF10	21.8	19.1	16.6	15.8

The trend graphs are as follows:

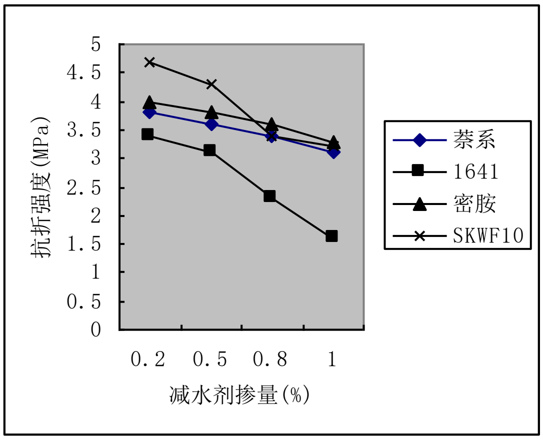


Figure 4.7 Effects of Superplasticizer Types and Dosages on the 3d Flexural Strength of Mortar

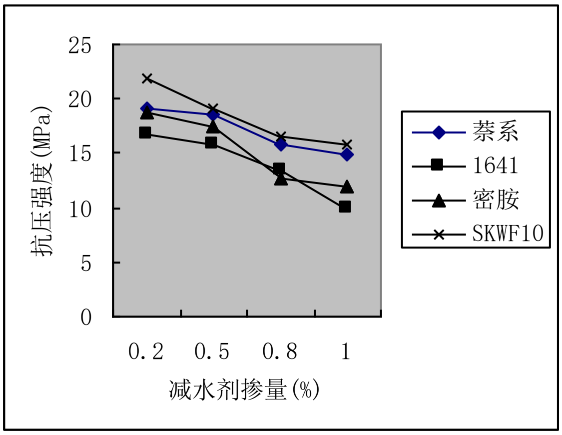


Figure 4.8 Effects of Superplasticizer Types and Dosages on the 3d Compressive Strength of Mortar

As can be seen from the data and trend graphs above, the effect of 1614 superplasticizer on the fluidity of mortar is the best, followed by naphthalene, better results for melamine superplasticizer, and the worst for SKWF10. But its impact on the early strength values shows an opposite trend, increasing successively. Thus, we can say that the effect of superplasticizer on the fluidity of mortar is significant. It can greatly improve the fluidity of mortar, but the early strength is reduced. Moreover, the early strength is reduced with the increase in the fluidity of mortar.

4.2.4 Effects of Adhesive on the Fluidity of Mortar

With ordinary strength mixing ratio, the naphthalene superplasticizer, the thickener of 2000 consistency (the dosage is 0.2‰ that of cement mass), ultra-fine sand of 0.60mm used for experiment, the comparative experiment on 3#, 4#, and 5#

adhesives is conducted. The test results after processing are as follows:

Table 4.7 Consistency Under Different Dosages of Adhesives (mm)

Types of Adhesives \ Consistency(mm) \ Dosage（%）	1.0	1.2	1.4	1.6
3#	97	100	103	106
4#	87	92	95	101
5#	91	94	100	106

Table 4.7 Degree of Expansion Under Different Dosages of Adhesives (mm)

Types of Adhesives \ Degree of Expansion (mm) \ Dosage（%）	1.0	1.2	1.4	1.6
3#	219.5	224.8	233.2	237.5
4#	209.3	219.5	223.8	225.0
5#	218.3	223.5	222.5	226.0

Its trend graphs are as follows:

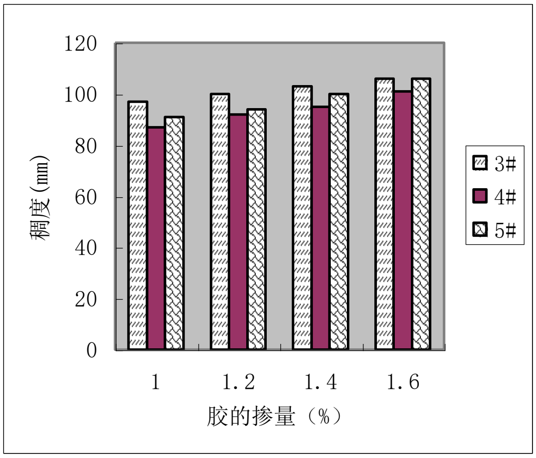


Figure 4.9 Effects of Adhesive Types and Dosages

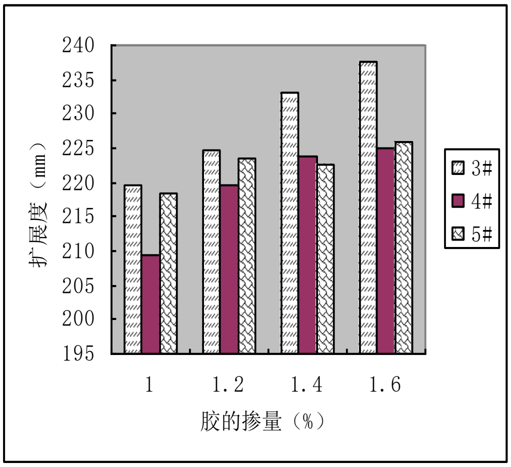


Figure 4.10 Effects of Adhesive Types and Dosages

on the Consistency of Mortar on the Consistency of Mortar

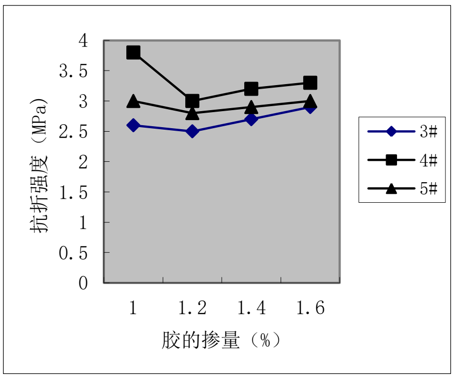
Table 4.8 3d Flexural Strength Under Different Dosages of Adhesives (MPa)

Dosage（%） Strength (MPa) / Types of Adhesives	1.0	1.2	1.4	1.6
3#	2.6	2.5	2.7	2.9
4#	3.8	3.0	3.2	3.3
5#	3.0	2.8	2.9	3.0

Table 4.8 3d Compressive Strength Under Different Dosages of Adhesives (MPa)

Dosage（%） Strength (MPa) / Types of Adhesives	1.0	1.2	1.4	1.6
3#	9.4	9.0	9.2	9.3
4#	15.7	12.7	13.0	13.3
5#	11.0	10.2	9.5	10.3

Its trend graphs are as follows:



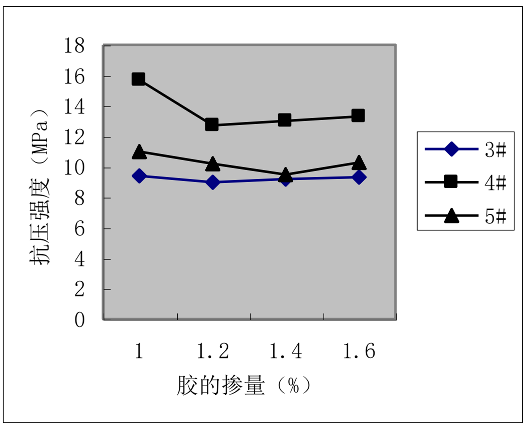


Figure 4.11 Effects of Adhesive Types and Dosages Figure 4.12 Effects of Adhesive Types and Dosages

on the 3d Flexural Strength of Mortar on the 3d Compressive Strength of Mortar

Table 4.9 3d Tensile Strength Under Different Dosages of Adhesives

Types of Adhesives \ Dosage（%） Strength (MPa)	1.0	1.2	1.4	1.6
3#	1.5	1.6	1.7	1.8
4#	1.9	2.0	2.2	2.3
5#	1.8	1.9	2.0	2.1

Its trend graphs are as follows:

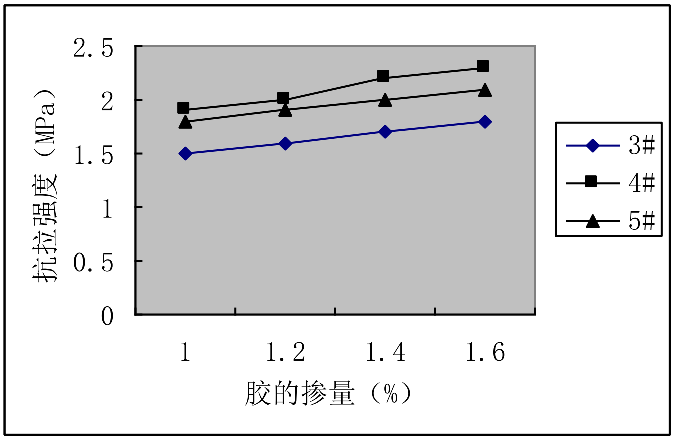


Figure 4.13 Effects of Adhesive Types and Dosages on the 3d Tensile Strength of Mortar

As can be seen from the experiment on the effects of adhesive types and dosage on the fluidity of mortar, the addition of adhesive has improved the cohesiveness and water retention of mortar. The early strength and fluidity will both increase with the increase of dosage. And the improving effects of 4# adhesive on the strength is the best, followed by 5#, and then 3#, but the improving effects on the fluidity is the opposite. However, the flexibility of mortar (measured by the ratio of compressive strength to flexural strength) has got greatly improved after adding the adhesives.

Table 4.10 3d Flexibility of Adhesives

Dosage（%） Flexibility Types of Adhesives	1.0	1.2	1.4	1.6
3#	3.5	3.6	3.4	3.2
4#	4.1	4.2	4.1	4.0
5#	3.7	3.6	3.3	3.4

In the improvement of flexibility, 4# adhesive has the best effects, which is also related to its maximum strength.

4.2.5 Effects of Fly Ash on the Fluidity of Mortar

With the ordinary strength mixing ratio used, the naphthalene superplasticizer and the thickener of 2000 consistency (the dosage is 0.2‰ that of cement mass) added, as well as the sand with the maximum particle size of 0.60mm used for experiment, the comparative experiment on different blending amounts of fly ash is conducted. The test data and conclusion analysis are as follows:

Table 4.11 Test Data of Fly Ash on Mortar Performance Indicators

Fly Ash Dosage（%）	Consistency（mm）	Degree of Expansion（mm）	3dFlexural Strength (MPa)	3d Compressive Strength (MPa)
0	61	18.3	4.2	15.7
10	73	19.5	4.0	14.5
20	69	19.9	3.4	13.7

30	63	20.2	3.3	11.6

The trend graph of its consistency and degree of expansion is as follows:

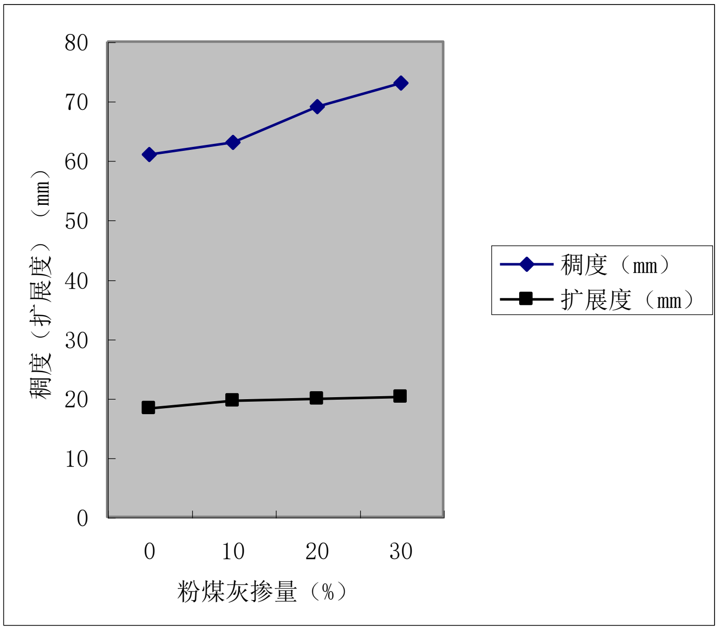


Figure 4.14 Effects of Fly Ash Dosages on the Consistency and Degree of Expansion of Mortar

In the case of the same water-adhesive ratio and addition of superplasticizer, the effects of fly ash dosage on the fluidity of mortar have been studied, and the results are seen in the above figure. As can be seen from the figure, the addition of fly ash enables the fluidity of mortar increase, and for the small addition of fly ash, the increase in its fluidity is more obvious. This is because fly ash is a mixed material of globular particles with the characteristics of pozzolanic reaction, and can have an effect on the fluidity of cement mortar from both physical and chemical aspects. In the physical aspect, the fly ash of globular particles can play a ball bearing lubricating role in the fluidity of mortar; from the chemical aspect, compared with cement, it has less adsorption of superplasticizers, and enables superplasticizers to fully improve the fluidity of mortar.

The trend graph of its strength is as follows:

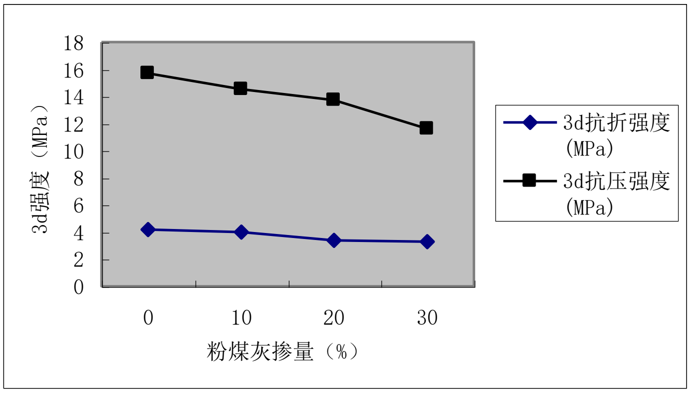


Figure 4.15 Effects of Fly Ash Dosages on the 3d Strength of Mortar

The test results show that with the increase in the addition amount of fly ash, the 3d strength of cement mortar will gradually be decreased. When the addition amount of fly ash is 40%-50%, the downward trend of strength is more obvious with the addition amount of fly ash. The test results also show that the early strength of mortar with the addition of fly ash is low, which is because there is a lack of connection between fly ash and slurry, between fly ash particles, and between fly ash and sand; the adsorption of mixing water on the surface of fly ash and sand will make the local water-cement ratio increase. If the addition amount of fly ash is increased, this effect is more significant, and thus the early strength is lower. In the late period, it can be improved by the strengthening of connection between the particles and the consumption of calcium hydroxide.

4.2.6 Effects of Thickeners on the Fluidity of Mortar

With the ordinary strength mixing ratio used, the naphthalene superplasticizer added, as well as the sand with the maximum particle size of 0.60mm, the comparative experiment on different kinds and addition amounts of thickeners is conducted. The test data and conclusion analysis are as follows:

Table 4.12 Data Records about the Effects of Thickeners on the Consistency of Mortar(mm)

Thickener Dosage（‰） Consistency(mm) Thickener Type	0.3	0.6	0.9	1.2
4000	79	77	68	68
20000	76	74	66	65
40000	72	72	63	63
100000	69	70	62	62

Table 4.13 Data Records about the Effects of Thickeners on the Degree of Expansion of Mortar(mm)

Thickener Dosage（‰） Consistency(mm) Thickener Type	0.3	0.6	0.9	1.2
4000	22.5	22.1	20.1	19.6
20000	22.3	21.8	20.0	19.2
40000	22.2	20.5	18.9	19.1
100000	21.8	19.8	18.4	18.5

Its trend graphs are as follows:

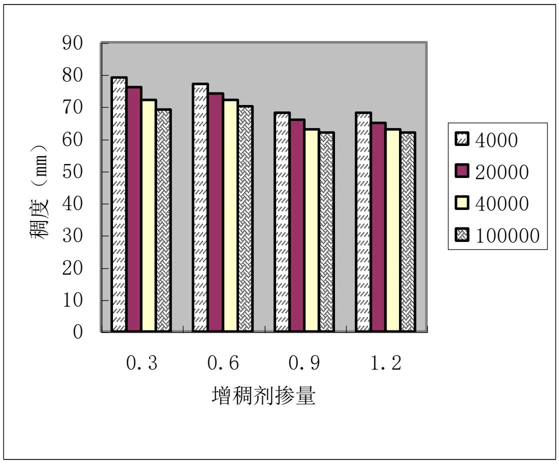


Figure 4.16 Effects of Thickeners on the Consistency of Mortar

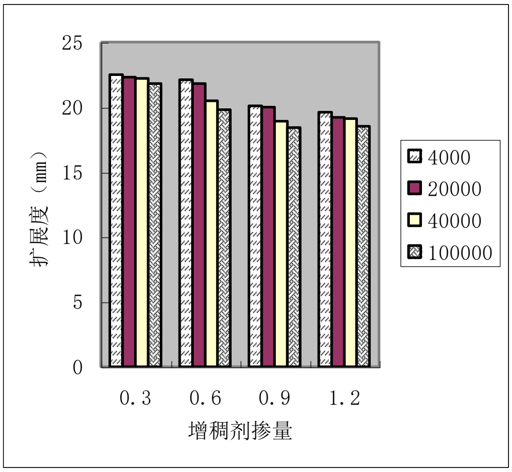


Figure 4.17 Effects of Thickeners on the Degree of Expansion of Mortar

As can be seen from Figure 4.16 and Figure 4.17, for the same kind of thickener, with the increase of the addition amount, the consistency and degree of expansion of mortar show a significant downward trend. While in the case of the same addition amount, the smaller the consistency of thickener is, the more obvious the improving effects on the consistency and degree of expansion will be.

Table 4.14 Data Records about the Effects of Thickeners on the 3d Flexural Strength of Mortar(MPa)

Thickener Type \ Thickener Dosage（‰） \ Strength (MPa)	0.3	0.6	0.9	1.2
4000	3.0	3.1	3.2	2.8
20000	3.5	3.2	3.2	2.7
40000	3.0	3.3	3.1	2.9

100000	2.8	3.3	2.9	2.9

Table 4.15 Data Records about the Effects of Thickeners on the 3d Compressive Strength of Mortar(MPa)

Thickener Dosage（‰） Strength (MPa) Thickener Type	0.3	0.6	0.9	1.2
4000	11.6	10.9	12.2	8.3
20000	10.2	10.5	10.4	9.1
40000	9.9	10.4	12.0	9.0
100000	9.0	10.8	10.0	10.0

Its trend graphs are as follows:

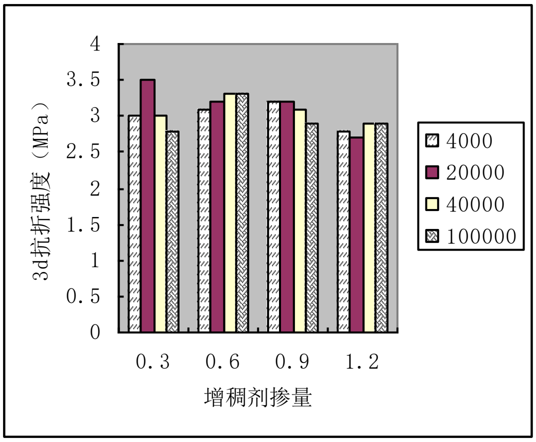


Figure 4.18 Effects of Thickeners on the 3d Flexural Strength of Mortar

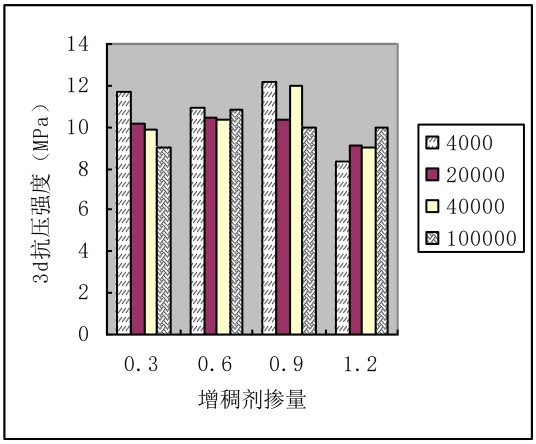


Figure 4.19 Effects of Thickeners on the 3d Compressive Strength of Mortar

As can be seen from Figure 4.18 and Figure 4.19, for the effects of thickeners on the strength of mortar, the phenomenon is not very evident, and there is no strong regularity. However, in the whole, the addition of thickener has still improved the early strength value of mortar.

For mortar, the main purpose of thickener is still to ensure good flow properties of mortar, prevent or reduce water loss of mortar. Add an appropriate amount of thickener in the mortar, due to the water retention effect of thickener, so that the free water is migrated and constrained, thereby reducing the frictional resistance between the particles. Although the thickener can make the viscosity of aqueous solution increased, as well as the frictional force between liquid molecules and solid particles increased, the increase in this resistance is much smaller than the frictional force between solid particles, so can effectively reduce the total shear force.

5 Conclusion

(1) The effects of water-reducing agent on the fluidity and strength of mortar is not only related to its kinds, but also to its dosage. When the fluidity of mortar is larger, the effect of superplasticizer is smaller, i.e., the difference between the kinds and the dosage is smaller. Conversely, when the fluidity of mortar is lower, the effect of superplasticizer is more obvious.

(2) The effects of sand gradation on the fluidity of mortar: the use of ultra-fine sand can well improve the workability of mortar, especially the improvement of fluidity.

(3) An equal amount of fly ash to replace cement can make the fluidity of fly ash mortar increased. The fluidity of mortar is not only related to the fineness of fly ash, but also to its dosage, and the maximum fluidity is decided by the both.

(4) The increase in the addition amount of fly ash makes the early strength of hardened paste reduced. The increase in the fineness of fly ash has a greater impact on the strength of hardened paste, and the lower the water-adhesive ratio is, the

more significant the dense packing and micro-aggregate effects of fly ash will be.

(5) For the effects of mortar mixing ratio on the fluidity of mortar, according to the relevant information, in the case of maintaining admixtures and other basic conditions unchanged, the larger the water-cement ratio is, the better the fluidity will be.

(6) The thickener has improved the fluidity of mortar, while enhancing the water retention of mortar and reducing the bleeding of mortar.

(7) The addition of adhesive has also well improved the fluidity of mortar, and the early flexibility of mortar has also got greatly improved.