Research on the Influence of the Mechanical Properties of Concrete Mixed with Different Mineral Admixtures

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Abstract

By studying the ratios of different mineral admixtures of single- and the double-admixed fly ash, and the concrete during the curing duration, and the influence of mineral admixtures amount and double-admixed ratio on the performance and mechanical properties of concrete, it shows that the workability of the concrete improves when mixed with a moderate amount of single- or double-admixed fly ash, usually less than 50% of the cement amount. No matter with single- or double-admixed admixtures, the 7d strength of fly ash and concrete mixed with mineral powder are lower than that of ordinary concrete, and the strength in the end stage is obviously higher, even higher when compared with ordinary concrete. With the increase of the amount of admixture, the increase rate of the strength of concrete mixed with single- and double-admixed admixtures rises, and the latter is better than the former. When the amount of the admixtures reaches a certain degree, the increase ratio of strength is low. At last, the optimal mix proportion is the excessive fly ash replaces 50% cement and concrete with 1/3 fly ash mineral powder.

Keywords

Fly Ash; Mineral Powder; Concrete; Mechanical Properties.

1. Introduction

With the development of China's economy, the scale of domestic construction industry is becoming larger and larger, ushering in the peak of infrastructure. Cement concrete is the main body of the building structure and the most used material in the construction. The production of cement consumes lots of energy, soil and other resources, discharging dust which pollutes water and air, and causes certain damage to the health of residents around the cement plant. Beside, as the industry and agriculture developing rapidly in recent years, the emission of industrial waste residues has reached a record high. However, these industrial wastes have not been effectively utilized. Hills of wastes have piled up, occupying farmlands and damaging the environment. To solve the problems, scholars at home and abroad began to study the use of industrial waste to replace a certain amount of cement or to add industrial waste to prepare concrete without reducing the amount of cement. By doing this, scholars found that industrial waste not only improves the performance of concrete, but greatly promotes the economy of construction and environmental protection[1~2]. Thus, it is significant to study the influence of industrial wastes as admixtures on the working performance of concrete.

In this thesis, by changing the ratio of mineral admixtures to replace cement and the ratio between fly ash and mineral powder, the influence of single- and double-admixed mineral admixtures on the physical and mechanical properties of concrete is studied.

2. Test Overview

Using equivalent and excessive amount of fly ash and mineral powder to replace the cement prepared concrete. The concrete without mineral admixture is defined as the blank group, number A0. The concrete that uses mineral admixture to replace a certain amount of cement is defined as the experimental group, and using the equivalent replacement method to replace 20%、30%、40%、50%、60% amount of cement with grade II admixed fly ash; and using the excessive replacement method (excess coefficient K_f=1.25) to replace 20%、30%、40%、50%、60% amount of cement with grade II admixed fly ash; after confirming the cement replacement amount, then the mineral powder added is in proportion to 1/4 and 1/3 amount of grade II fly ash. Next, numbered the 20 groups as B1-B5, C1-C5, D1-D5, and E1-E5. All concrete specimens in the test are cube with a size of 100mm×100mm×100mm. All the concrete specimens are cured under standard conditions. The curing durations are 7d, 28d, 60d, 90d and 180d respectively. All above are used to reflect the short-, medium- and long-term mechanical properties of concrete.

2.1 Test Raw Materials

2.1.1 Cement

The Portland cement was produced by a cement plant in Sichuan, the type is P·O42.5. The cement nature is illustrated in the following Table 1.

Table 1The Physical Characteristics of Cement

Cement Fineness (%) (80μm sieved)	Normal Consistency (%)	Pat test	Setting Time (min)		Bending Strength (Mpa)		Compression Strength (Mpa)	
			Initial	Finally	3d	28d	3d	28d
1.6	26.5	Qualified	120	370	4.8	8.3	27.6	42.9

2.1.2 Fly Ash

The fly ash was produced by a power plant in Sichuan, which is black powder and well packaged. The density is 2.42g/cm^3 , and the activity index of 28d is 89.0%, and the fineness is 80 μ m, and the sieve residue is 3.5%. The chemical composition is illustrated in the following Table 2.

Table 2 Chemical Composition of Fly Ash

Composition	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	TiO_2	Na_2O	K_2O
Content	49.37%	27.86%	8.68%	2.52%	2.43%	0.86%	0.25%	0.28%

2.1.3 Mineral Powder

The types and related performance of mineral powder is illustrated in the following Table 3.

Table 3 Types and Related Performance of Mineral Powder

Origion	Densit(g/cm^3)	SSA(m^2/kg)	Water Content(%)	Activity Index(28d)(%)
Qingdao Alkali Industry Company	2.83	404	0.14	89.0

2.1.4 Fine Aggregate

The fine aggregate is from river sand in Sichuan, grade II. The apparent density is 2.62g/cm^3, and the mud content is 1.9%, and the sediment content is 0.4%. The nominal aggregate size and value of each cumulative percentage of sieve residues are illustrated in the following Table 4.

Table 4 Grade II Sand

Mesh Size (mm)	Scope of cumulative percentage of sieve residue (%)	Separate percentage of sieve residue (%)	Cumulative percentage of sieve residue (%)
4.75	10~0	2	2
2.36	25~0	9	11
1.18	50~10	10	21
0.6	70~41	30	51
0.3	92~70	28	79
0.15	100~90	21	100

According to the Table 4, the fineness modulus of fines is 2.57, medium sand.

2.1.5 Coarse Aggregate

Continuous graded crushed stone is selected as the coarse aggregate for preparing concrete test pieces, with the particle size of 5mm-31.5mm. The each cumulative percentage of sieve residues is shown in Table 5. The apparent density is 2.65g/cm^3, the needle content and flake is 6.0%, the mud content is 0.4%, and the crushing index is 11.3%.

Table 5 Continuous Grading of Coarse Aggregate with Nominal Size of 5-31.5mm

Mesh Size (mm)	Scope of cumulative percentage of sieve residue (%)	Separate percentage of sieve residue (%)	Cumulative percentage of sieve residue (%)
2.36	95~100	2	100
4.75	90~100	9	98
9.5	70~90	67	89
16.0	—	—	—
19.0	15~45	21	22
26.5	—	—	—
31.5	0~5	1	1

2.1.6 Additive

Water reducing agent comes from polycarboxylic acid water reducing agent produced by a company in Sichuan.

2.1.7 Water

The water used in this test conforms to GB5749-2006.

2.2 Test Method

2.2.1 Test on the Performance Concrete Mixture

According to GB / t50080-2016 Test Method for Performance of Ordinary Concrete Mixture[3], I evaluate the mix and workability with the slump and the slump expansion. The unit of slump is mm. During the test, the fluidity, cohesiveness and water holding capacity of concrete mixture shall be observed at the same time.

2.2.2 Test on the Compression of Concrete Block

According to the method proposed in the corresponding specifications, the compression strength of the tested cubic blocks with the size of 100mm × 100mm × 100mm is measured at the standard curing conditions with the temperature of (20±2)℃ and the relative humidity of more than 95%, and the curing duration is 7d , 28d, 60d , 90d and 180d.

2.3 Mixture Ratio

According to JGJ55-2011 Code for Mixture Ratio of Ordinary Concrete[4], the standard mixture ratio of C40 blank group concrete is illustrated in the following Table 6.

Table 6 C40 Standard Concrete Mixture Ratio（Unit：kg/m^3）

Number	Water-cement ratio	cement	Sand ratio（%）	Fine aggregate	Coarse aggregate	water	Water reducing agent（%）
A0	0.46	377	47	851	960	175	1.2

According to the different proportion of mineral admixtures to replace cement and the different proportion of fly ash to mineral powder, I can calculate the mixture proportion of C40 concrete with admixtures illustrated in the following Table 7. In the Table, B represents the replacement of cement by single-admixed of fly ash, C represents the replacement of cement by single-admixed of fly ash, D represents the replacement of cement by double-admixed of 1:4, E represents the replacement of cement by double-admixed of 1:3, 1, 2, 3, 4, and 5 represent fly ash content of 20%, 30%, 40%, 50% and 60% respectively.

Table 7 Mixture Ratio of Concrete with Admixtures

Number	Water Binder Ratio	Cement	Fly Ash	Mineral Powder	Sand Ratio(%)	Fine Aggregate	Coarse Aggregate	Water	Water Reducing Agent(%)
B1	0.46	302	75	-	47	851	960	175	1.2
B2	0.46	264	113	-	47	851	960	175	1.3
B3	0.46	226	151	-	47	851	960	175	1.4
B4	0.46	189	188	-	47	851	960	175	1.4
B5	0.46	151	226	-	47	851	960	175	1.6
C1	0.44	302	94	-	46	831	960	175	1.2
C2	0.43	264	141	-	46	820	960	175	1.3
C3	0.42	226	189	-	46	810	960	175	1.4
C4	0.41	189	236	-	45	800	960	175	1.6
C5	0.40	151	283	-	45	790	960	175	1.9
D1	0.42	302	94	24	46	831	960	175	1.1
D2	0.40	264	141	35	46	820	960	175	1.3
D3	0.38	226	189	47	46	810	960	175	1.3
D4	0.36	189	236	59	45	800	960	175	1.5
D5	0.35	151	283	71	45	790	960	175	1.9
E1	0.41	302	94	31	46	831	960	175	1.1
E2	0.39	264	141	47	46	820	960	175	1.3
E3	0.37	226	189	63	46	810	960	175	1.3
E4	0.35	189	236	79	45	800	960	175	1.4
E5	0.33	151	283	94	45	790	960	175	1.9

3. Test Results

3.1 Working Performance of Concrete with Mineral Admixtures

According to the relevant specifications, the slump and slump expansion (that is, the diameter of the concrete admixtures when it is stable in slump) can be used to evaluate the working performance of concrete with mineral admixtures. That is, using the traditional method to measure the slump and the slump expansion at the same time to accurately judge the fluidity of concrete mineral admixtures. As the flow direction of the slump expansion is all round, it is necessary to measure the diameter of two directions and find the average value to confirm. The workability of concrete with mineral admixtures is detailed in the following Table 8.

Table 8 Workability of Fresh Concrete

Number	Slump (mm)	Slump expansion (mm)	Workability	Number	Slump (mm)	Slump expansion (mm)	Workability
A0	160	400	Qualified	D1	230	565	Good
B1	180	430	Good	D2	235	540	Good
B2	210	550	Good	D3	240	500	Good
B3	220	560	Good	D4	230	495	Good
B4	210	500	Good	D5	225	510	Good
B5	200	500	Good	E1	230	555	Good
C1	215	500	Good	E2	235	520	Good
C2	220	550	Good	E3	230	505	Good
C3	235	530	Good	E4	225	525	Good
C4	235	535	Good	E5	210	510	Good
C5	225	535	Good				

Combined the spot mixing results and Table 8 and Picture 1 with the spot mixing results, after the admixtures were added to the concrete, the working fluidity of the fresh concrete increases, the cohesiveness and water holding capacity are also higher than those of the ordinary concrete admixtures, and the working performance of the ordinary concrete admixtures are relatively poor; the working performance of the concrete admixed with fly ash and mineral powder is generally better than that of the concrete admixed with fly ash, because the composite effect of these two kinds of admixtures improves the fluidity of concrete. The particles of mineral powder are irregular in shape and rough in surface, and have a large adsorbability for water. When fly ash admixed with concrete, the fluidity of fresh concrete will be reduced. At the same time, the internal friction is also reduced by fly ash, which helps to increase the fluidity of concrete. Thus, the double admixture of fly ash and mineral powder can pose complementary effect to shape and morphology[5].

The fluidity of concrete depends on the characteristics of each component and its relative content, especially the effect of water, while fly ash has a certain impact on the water consumption of concrete. The water demand of fly ash is close to that of Portland cement, even smaller than Portland cement. When the water demand ratio of fly ash is smaller, the water consumption of concrete is smaller. When fly ash and mineral powder are added to concrete, the flow of concrete will be improved under the same water consumption. On the one hand, because the shape of fly ash particles is mostly spherical glass with smooth surface which lubricates fines and paste, and these small fly ash particles can fill in the gap between cement particles which reduce the filling water. On the other hand, due to the hydrophilic effect of fly ash glass particles, a layer of water film is formed, so that a large proportion of admixing water can be widely distributed and stay in the whole concrete, which is conducive to prevent the occurrence of concrete bleeding and improve the workability of concrete. In addition, the workability of fresh concrete can be improved by adding some water reducing agent. Generally, as the admixture content increasing, the fluidity of concrete admixture will continue to rise due to the role of mineral admixture and water reducing agent, but in the above Tables, the slump of D5-E5 groups concrete decrease, because when the admixture content reach a certain extent, as the specific surface area of admixture increasing, the increment of water consumption exceeds the admixtures water reducing capability.

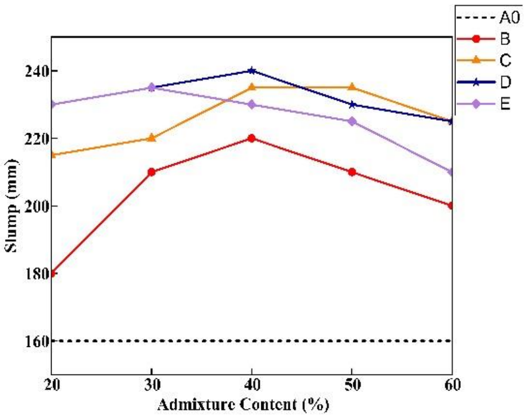

Fig. 1 Effect of Mineral Admixtures on Slump

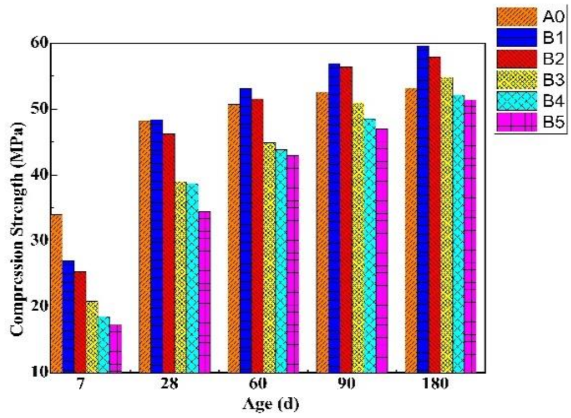

Fig. 2 Influence of Fly Ash Content on Strength (Equivalent Method)

3.2 Research on the Development Law of Compression Strength of Concrete Admixed with Mineral Admixtures

3.2.1 Analysis of the Influence of Fly Ash on Strength

Fly ash, as a good mineral admixture, has been widely applied to practice. The influence of different amount of fly ash in different ages on the compression strength of concrete is illustrated in Fig. 2 and Picture. 3. It can be seen from Fig. 2 and Fig. 3 that the compression strength of concrete admixed with fly ash in each test age decreases with the of fly ash content increasing. In the early stage, no matter how much fly ash content is, the strength of concrete admixed with fly ash is smaller than that of ordinary concrete. As age rising, the growth rate of strength of concrete admixed with fly ash is accelerated. The strength of concrete with fly ash replacing 20% cement is higher than that of ordinary concrete, and the strength of 180d is 1.1 times of that of ordinary concrete. As the content of concrete admixed with fly ash, the strength decreases slightly. When the content reaches 40%, the short-term strength is lower than that of ordinary concrete, the strength of 180d is still slightly higher than that of ordinary concrete instead. The strength of the concrete is lower than that of the ordinary concrete when the content is more than 40%. When adopting the excessive replacement method, the concrete strength is higher than that of the equivalent replacement method. From Fig. 4, it can be seen that the 28d strength of the concrete admixed with fly ash that excessively replaces 40% cement is the same as that of the ordinary concrete. As for long-term strength, the amount of fly ash can be as high as 50%, and its strength development rate is relatively fast.

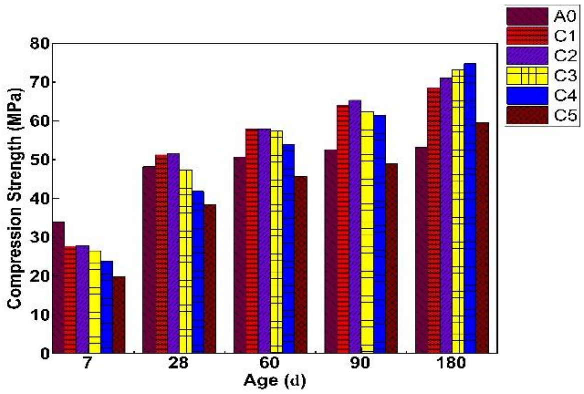

Fig. 3 Influence of Fly Ash Content on Strength (Excessive Replacement Method)

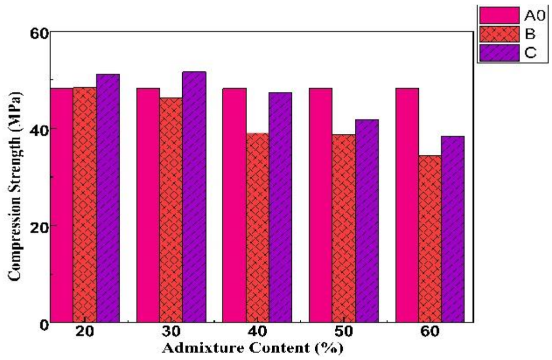

Fig. 4 Comparison of the Influence of Fly Ash Content of Two Replacement Methods on Strength at 28 Age

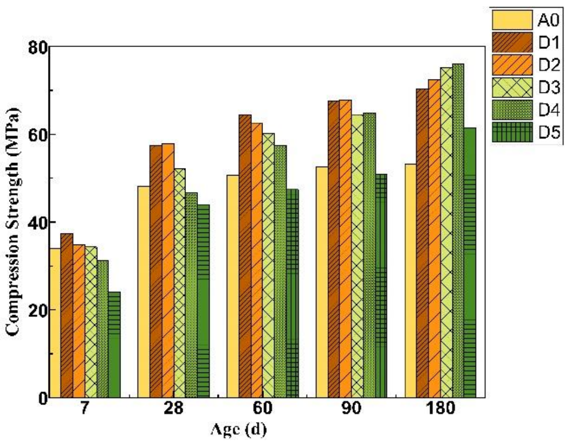

Fig. 5 The Influence of 1:4 Ratio of Two Admixtures on Strength

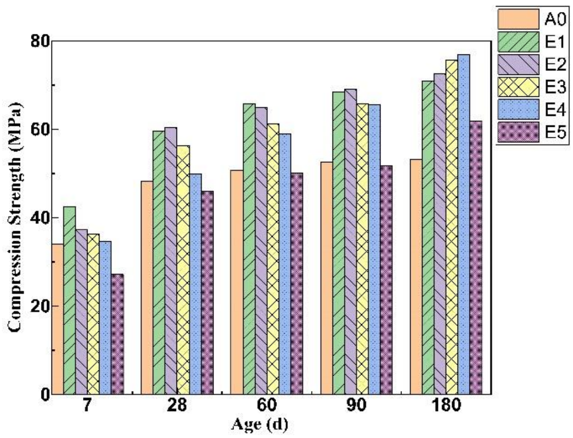

Fig. 6 The Influence of 1:3 Ratio of Two Admixtures on Strength

There are two reactions between fly ash and cement, one is the hydration reaction of cement clinker, the other is the secondary hydration reaction of the active component in fly ash and calcium hydroxide [6]. Generally, the hydration reaction of cement is prior. Only when a large amount of calcium hydroxide is released from the hydration of cement, the active component of fly ash can absorb calcium ion. The surface layer of fly ash micro glass bead is destroyed, and the $Ca(OH)_2$ and C-S-H inclusions formed on the surface of fly ash particles are relatively slow. Therefore, in the early stage of hardening of fly ash concrete, the cementation coefficient β is small[7], and the gelation of fly ash has little contribution to the early strength of concrete. Besides, the early strength of concrete is mainly affected by the degree of hydration reaction of cement. As the fly ash content increasing, the cement particles are fully diluted by it, which further hinders the development of strength in the early stage. However, as the age rising, cement hydrated to generate enough amount of $Ca(OH)_2$, the potential activity of fly ash is gradually activated, gelation action is more and more obvious, and more and more C-S-H gel is generated, which makes strength in the late stage of concrete increase rapidly. When fly ash is added to the concrete by using the method of excessive replacement, the amount of fly ash increased and the amount of cement relatively reduced, which makes the hydration reaction rate of cement clinker increase and promotes the pozzolanic reaction of fly ash, so the strength in the early stage of concrete admixed with fly ash improved. In addition, As the fly ash content increasing, the number of fine particles in fly ash particles will increase, which is easier to combine with gel materials and strengthen the densification of gel materials and aggregate interface, which is more conducive to the development of fly ash strength[8].Thus, compared with the equivalent replacement method, the excessive replacement method is better.

3.2.2 Analysis of the Influence on the Strength of Concrete Admixed with Fly Ash and Mineral Powder

It is concluded that the strength of the concrete made by the method of excessive replacement is better. In this test, mineral powder is admixed on the basis of the admixtures ratio of the excessive concrete admixed with fly ash, and the compassion of strength of concrete admixed with fly ash, concrete admixed with fly ash and mineral powder and ordinary concrete is illustrated in Fig. 5 to Fig. 8. It can be seen from Fig. 5 to Fig. 6 that after adding 1 / 4 of the amount of fly ash, the development rate of strength accelerates, and when fly ash excessively replaces cement, the strength of concrete admixed with no more than 40% fly ash is higher than that of ordinary concrete at all ages. When the amount of mineral powder is increased, the strength of E1-E4 concrete is higher than that of ordinary concrete. From the perspective of long-term strength, regardless of the proportion of the two admixtures, the strength of concrete is ultimately higher than that of ordinary concrete. From Fig. 7, when the ratio of mineral powder and fly ash is 1:3, the strength of double-admixed concrete is higher than that of 1:4. The 28d strength of concrete with fly ash replacing 50% cement and compounding 1/3 mineral powder is 3.5% higher than that of ordinary concrete. It can be seen from figure 8 that the strength of double-admixed concrete is higher than that of single-admixed concrete, and it increases in proportion to mineral powder content.

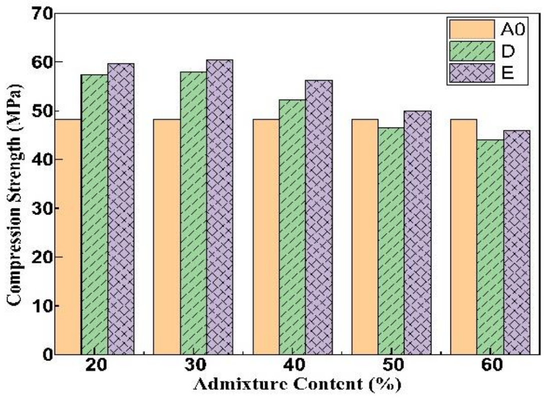

Fig. 7 Comparison of Concrete Admixed with the Two Admixtures at 28d Age

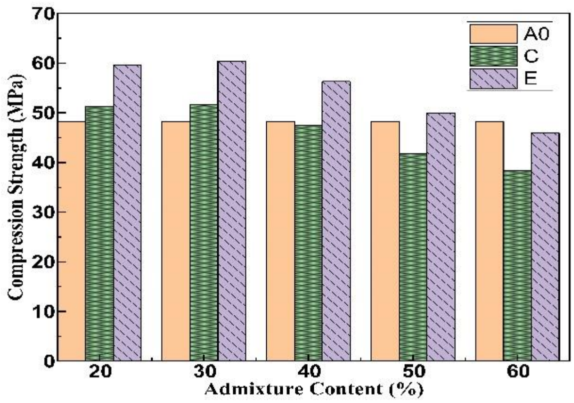

Fig. 8 Comparison of Concrete Admixed with the One Admixture at 28d Age

Some properties of concrete can be improved by adding fly ash to concrete, but in the case of high content, because the pozzolanic effect of fly ash lags behind the reaction of cement, and the chemical activity is relatively reduced, which makes the interfacial adhesion between pozzolanic particles not strong, resulting in the strength in the early stage of concrete will be reduced. The interface structure of aggregate and paste is improved by adding mineral powder. Because the activity of mineral powder is higher than that of fly ash, the content of calcium oxide is much higher than that of fly ash, and more calcium hydroxide is generated by reacting with water, which improves the pozzolanic effect and hydration reaction, and enhances the interaction of chemical reaction between particles in concrete, and thus promotes the strength in the early stage. The activity of mineral powder is different from that of fly ash. The pozzolanic reaction of fly ash is a secondary reaction process, while the pozzolanic reaction of mineral is a primary reaction process. Its mineral composition can directly react with water to generate hydration products, and then hardens. So when fly ash and mineral powder are added to concrete at the same time, fly ash and mineral powder complement each other in strength, showing the advantages that single mineral admixture does not possess, effectively making up for the shortcomings of the lack of early strength of concrete admixed with fly ash, and improving some properties of concrete, such as the working performance of concrete (water holding capacity, cohesiveness, and workability). The concrete structure will become more compact after hardening, making the durability of concrete such as impermeability, frost resistance and chemical corrosion resistance significantly improved, and the complementary effect of advantages better, and the advantage of complementarity more obvious.

4. Conclusions

(1)After adding fly ash and mineral powder admixtures to concrete, the working performance of concrete has been greatly improved, and its cohesiveness, water holding capacity and slump are better than that of ordinary concrete. However, the admixing amount should not be too much. If the water demand is increased due to the increase of the specific surface area of the admixture, the fluidity will be reduced and the workability will be affected, which should be controlled within 50% of the cement content, usually.

(2)The strength in the early stage of ordinary concrete admixed with fly ash is lower than that of ordinary concrete admixed with nothing, but the development trend of strength is faster, and the later strength will be higher than that of ordinary concrete. For the concrete admixed with fly ash by using equivalent replacement method, according to the curing duration of concrete, under the condition of reaching the design strength of C40 concrete, the maximum amount of fly ash can be as high as 40%. The strength growth rate and amplitude of fly ash by using the excessive replacement method are higher than that equivalent replacement method.

(3)For the concrete admixed with mineral powder on the basis of excessive replacement of fly ash, the properties of low strength in the early stage of concrete admixed with fly ash are improved. If the fly ash exceeds 50% amount of cement, and the mineral powder is 1 / 3 of fly ash, the strength at 28d age is still slightly higher than that of ordinary concrete, then 50% amount of cement can be saved to reach the same concrete strength.

(4)Adding fly ash and mineral powder to concrete can save certain cement, reducing concrete cost, a lot of energy consumption and greenhouse gas CO_2, which is beneficial to environmental protection and has certain economic and social benefits.

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