Research on The Effect of External Admixture on The Micro-structure and Performance of Concrete under The Plateau Conditions

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Abstract. In order to satisfy the requirements of the complex environment of plateau on the use of concrete mechanical properties and durability performance, this paper designed three different mix-ratio concretes of 30% fly ash, 30% fly ash + 5% silica fume slurry and 30% fly ash + liquid internal curing agent. And analyzed the change rule of concrete compressive strength, shrinkage, impermeability and microscopic properties. The results showed that the 56d compressive strength of concrete with 5% silica fume slurry and internal curing agent decreased by 3.2% and 4.0%, respectively, compared with 30% fly ash alone, while the internal curing agent improved the early shrinkage of the concrete. 30% fly ash + 5% silica fume slurry ratio of concrete better improved the pore structure, morphology, physical composition, and seepage resistance of the concrete. Finally, based on the entropy weighting method, the performance of concrete under the three ratios was evaluated comprehensively, and 30% fly ash + 5% silica fume slurry was obtained as the optimal ratio, and it is recommended that fly ash + silica fume slurry be added to improve the working performance of the concrete and prolong its service life in the plateau environment.

Keywords: low air pressure, external admixture, mechanical properties, durability, microstructure

1 Introduction

The construction scale of China's transportation infrastructure is expanding, and in the context of the “Belt and Road” initiative and the regional coordinated development strategy, the concrete structural engineering in the western plateau area is receiving more and more attention. The Tibetan Plateau is the largest plateau in China and the highest altitude in the world, with an average altitude between 4000 and 5000 m. The average air pressure is more than 30% lower than that of the plains, and the solar radiation is strong, and the annual sunshine number can reach 2200~3600h [1]. Plateau environment special climatic conditions will adversely affect the performance of concrete, low air pressure environment will accelerate the evaporation of water on the surface of the concrete, causing the migration of water within the concrete, resulting in the

G. Zhao et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Architecture and Urban Engineering (ICCAUE 2024)*, Advances in Engineering Research 262,
https://doi.org/10.2991/978-94-6463-688-8_31

concrete pore structure and interface transition zone due to insufficient hydration to produce deterioration[2]. Dry, strong wind environment will further aggravate the shrinkage cracking of concrete, affecting the performance of concrete [3]. In complex engineering environments, concrete properties are often improved by adjusting the mix ratio and curing methods, while for some larger structures (such as bridge piers, etc.), the applicable curing methods are limited. In order to improve the performance of concrete, to meet the requirements of the harsh environment of the plateau on the working performance of concrete, through the mixing of admixtures to adjust the concrete proportion is essential to improve the mechanical properties and durability of concrete.

Admixtures such as fly ash and silica fume are added to concrete instead of part of the cement, which can not only alleviate the problem of carbon emission, but also reduce the water-cement ratio of concrete, optimize the pore distribution of the cement paste, and improve the volumetric stability and homogeneity of the concrete, thus improving the mechanical properties of concrete [4]. However, a lower water-cement ratio usually results in a dense concrete structure with poor permeability, difficult access of moisture from the outside, and low relative humidity inside, which in turn causes self-shrinkage of concrete [5]. By introducing internal curing materials inside the concrete, additional curing moisture can be provided to the concrete to maintain the relative humidity inside the concrete, improve the moisture distribution and wetting state, promote cement hydration, reduce the early self-shrinkage of the concrete, and inhibit the generation of cracks, thus improving the durability and mechanical properties of the concrete [6].

Based on the above, this paper designs three mixing methods: single mixing of fly ash, mixing of fly ash and silica fume, and mixing of fly ash and internal curing agent, to study the effects of the three types of mixing ratios on the microscopic pore structure, hydration state and macroscopic properties of concrete in plateau environment. In addition, the performance of the three types of concrete mixes was analyzed with fuzzy mathematical theory to provide technical support and theoretical basis for the design and construction of concrete structures in plateau environment.

2 Test Program

2.1 Test Materials

The cement used in the tests is P.O42.5 ordinary silicate cement, with a specific surface area of $320m^2$ /kg and a 3d compressive strength of 26.5MPa; the fly ash is the second-grade fly ash. Coarse aggregate is 5~31.5mm continuous graded gravel produced at the project site, with an apparent density of $2710kg/m^3$. Water reducing agent and air-entraining agent are produced by Yunnan Shanfeng Industry and Trade Co. Silica fume slurry is a kind of compacting-enhancing anti-cracking agent developed by Beijing Tieke Construction Technology Co., Ltd. for the second lining concrete of bridges and tunnels, which is prepared by mixing nano-particle silica fume, chemical dispersant and water in a certain proportion and then adopting special dispersing process, and when it is used in combination with large dosage of fly ash, the compactness of concrete can be increased effectively and the drying shrinkage value of concrete can be reduced, so as to significantly enhance the anti-cracking ability of concrete. The performance of silica fume slurry meets the provisions of "Silica Fume for Mortar and Concrete" GB/T27690-GB/T 27690-2023. Inner curing agent is a new type of liquid inner curing agent developed by Shandong Zhengheng New Material Technology Company Limited.

2.2 Specimen Preparation

The test materials include cement, fly ash, silica fume slurry, internal curing agent, fine aggregate, coarse aggregate, water reducer, air-entraining agent and water. Liu et al (2014) found that by comparing the mechanical properties of concrete at different fly ash dosages, the peak compressive strength of specimens at all ages was reached when the fly ash dosage was 30%7. Therefore, the admixture of fly ash in this study was designed as 30%. A total of three mixing ratios were designed for the test, as shown in Table 1, C_{I} concrete was single mixed with 30% fly ash, C_{II} concrete was double mixed with 30% fly ash + 5% silica fume slurry, and C_{III} concrete was double mixed with 30% fly ash + internal curing agent. The concrete was tested by pouring 100mm×100mm×100mm cubic specimens, 100mm×100mm×515mm prismatic specimens and φ100mm×50mm cylindrical specimens respectively.

Table 1. Ratio design

Sample No	Cement	Fly ash	Silica Fume Slurry	Internal maintenance agent	fine aggregate	coarse aggregate			Water reducing agent	air-entraining agent	water
						5-10 mm	10-20 mm	16-31.5 mm			
C_{I}	294	126	/	/	803	204	511	306	4.2	2.1	150
C_{II}	279	126	30	0	803	204	511	306	4.2	2.1	135
C_{III}	284	126	0	12	803	204	511	306	4.2	2.1	150

2.3 Test Methods

The average air temperature at the test site was 10±2°C, air pressure was 65±5kPa and humidity was 45±5%. The compressive strength, shrinkage, impermeability, porosity, microscopic morphology and physical composition of concrete specimens under different admixture ratios were tested to investigate the macro and micro properties of concrete specimens under different admixture ratios.

Compressive Strength Tests.

According to the specification GB/T50081-2002 "Standard Test Methods for Mechanical Properties of Ordinary Concrete", the electro-hydraulic servo press is selected to test the cubic compressive strength of 100mm×100mm×100mm concrete specimen.

The test is continuously and uniformly loaded, and the loading speed is controlled as 0.5MPa/s. The cubic compressive strength of the standard specimen (150mm×150mm×150mm) can be obtained by inputting the specimen size and conversion coefficient.

Shrinkage Tests.

According to the specification GBT50082-2009 "Standard for Long-term Performance and Durability Test Methods of Ordinary Concrete", the contact deformation tester was used to test the shrinkage deformation of 100mm×100mm×515mm prisms at different ages, and the average value of three specimens in each group was taken as the shrinkage value of the specimens.

Impermeability Tests.

According to the specification GB/T50082-2009 "Standard Test Methods for Long-term Performance and Durability of Ordinary Concrete", the electric flux value of the cylindrical specimen was measured. Before the test on the specimen for vacuum water retention and seal the cylinder side, after the specimen is installed into the test box, 6 h after the specimen to record the electric flux value, the larger the electric flux value on behalf of the concrete impermeability performance is worse.

Microscopic Property Tests.

The pore structure of concrete was tested using a multifunctional nuclear magnetic resonance microstructure analyzer from Suzhou Neumay Analytical Company. Before the test started, the 100mm×100mm×100mm cubic specimen was placed in the vacuum pressurized device for pressurized water saturation for 24h, and the H protons in the pore water were detected by NMR technology, and the size of the concrete pore size was converted by the relaxation time T_2, and the T_2 spectra were transformed into the porosity to analyze the microscopic pore structure of the concrete.

Adopted the field emission SEM5000 electron microscope produced by Guoyi Quantum to carry out scanning electron microscope test, and selected the broken pieces after compression damage in the compression test, with a sample volume of about 1cm3. Before the test, the specimen was soaked in ethanol solution for 24h to stop hydration, and then placed in a vacuum drying box at 40°C for backup, and then electron scanning was carried out for observation of its microscopic morphology after gold-plating.

The XRD test was carried out using a Rigaku bench-top line diffractometer Miniflex 600. The blocks to be tested were crushed and ground into powder form, and then put into the X-ray diffractometer for scanning and analysis to obtain their physical phase composition.

3 Resulis and Analysis

3.1 Analysis of Concrete Compressive Strength

The concrete compressive strength test photographs are shown in Fig. 1, and the growth of compressive strength of concrete with age at 3d, 7d, 14d, 28d and 56d for the three ratios are obtained. As can be seen from Fig. 2, with the increase of age, the compressive strength shows different growth rates, and the compressive strength of C_{II} concrete is the fastest. 7d before the age of C_{III} concrete has the highest compressive strength, followed by the strength of C_{II} concrete, and the strength of C_{I} concrete is the smallest; 7d after the age of C_{II} concrete, the compressive strength of C_{II} concrete develops rapidly, and the compressive strength of C_{II} concrete increases 5.7% compared with that of single-mixed fly ash, and the compressive strength of concrete increased 5.8% after the increase of 5% silica fume slurry. Compared with the single-mixed fly ash, the 28d compressive strength of concrete increased by 5.4% when adding 5% silica fume slurry, and the 56d compressive strength increased by 3.3%; the 28d compressive strength of concrete decreased by 4.6% when adding internal curing agent, and the 56d compressive strength decreased by 4.4%. When appropriate amounts of fly ash and silica fume are added to concrete in plateau environments, the cement content will be reduced accordingly, the water requirement for the hydration reaction will be lowered, and the effect of water loss in concrete caused by low atmospheric pressure and low humidity will be attenuated to some extent. When the content of internal curing agent is added higher, although the number of internal cementing pores of concrete increases, the number of large capillary pores, which have a greater impact on the strength of concrete, also increases, and the corresponding total porosity of concrete increases, so it will adversely affect the strength of internally cured concrete. At the same time, the moisture dissipation caused by low air pressure and low humidity takes some time, so the difference between the compressive strength of the concrete in the early stage is not big, and after the age of 14d, the advantage of 30% fly ash + 5% silica fume concrete starts to be reflected compared with the other two groups. For the early strength of concrete, the 7d strength of C_{I}, C_{II} and C_{III} concrete is only 57%, 61% and 44% of the 28d strength. Analyze the reason, when mixing fly ash and silica fume slurry and other admixtures will reduce the amount of cement, in the hydration reaction of the cement reaction in the early stage is small, resulting in the strength of the concrete specimens in the early stage is low, when the fly ash occurs in the second hydration reaction, it can absorb the un-reacted $Ca(OH)_2$, the formation of C-S-H gel, to improve the specimen densification, increasing the strength of the late stage. Compared with the other two ratios, the mixing of internal curing agent can promote the occurrence of the pre-hydration reaction to a certain extent, which is manifested in the enhancement of the strength in the early stage.

Fig. 1. Compressive strength test

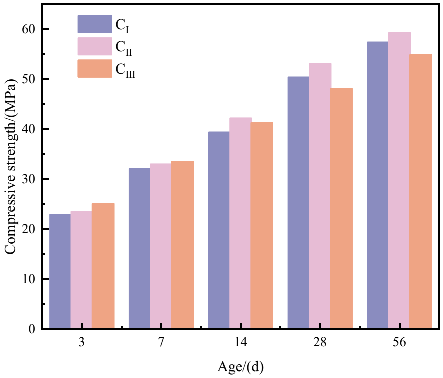


Fig. 2. Compressive strength of concrete with different ratios

3.2 Analysis of Concrete Shrinkage

The shrinkage strain values of the concrete specimen blocks are shown in Fig.3. It can be seen that the development of concrete shrinkage strain values in the early stage of cement hydration under the three mix ratios are all more drastic, and the 56d shrinkage of $C_{I,}$ C_{II} and C_{III} concrete is 72.5%, 81.9% and 82.1% of the 120d, respectively, and the shrinkage strain values tend to be gradually stabilized with the growth of the age of curing. Silica fume slurry and internal curing agent improved the early shrinkage of fly ash-added concrete to different degrees, compared with C_I concrete, the 56d shrinkage strain of concrete added with 5% silica fume slurry and internal curing agent decreased by 2.7% and 5.6%, respectively, and internal curing agent reduced the shrinkage strain of concrete better than that of 5% silica fume slurry at each age. Usually larger shrinkage leads to cracks in the concrete and adversely affects the effectiveness of the concrete. When fly ash is used as a cement admixture it can replace part of the cement and reduce the amount of cement in the concrete, which reduces the hydration products of the concrete and makes the shrinkage deformation of the concrete smaller. When fly ash and silica fume slurry mixed with less cement content, reduce the generation of heat of hydration, thus reducing the shrinkage of concrete; mixed with internal curing agent can form a film in the concrete, not only to prevent the evaporation of water inside the concrete, to maintain the hydration reaction of cement, and the formation of the protective film can reduce the dry cracks on the surface of the concrete, reducing the tendency of shrinkage of the concrete. Compared with $C_{I,}$ C_{II} concrete, C_{III} concrete shrinkage reduction effect is most obvious. Plateau environment of low humidity, low air pressure will accelerate the concrete surface water loss, resulting in concrete from the inside to the outside of the water migration, concrete internal humidity will be further reduced. The reduction of internal humidity is one of the important reasons for the contraction of concrete, therefore, due to the "water retention effect" of the internal curing agent, in the plateau environment of concrete, compared with C_I, C_{II} concrete, C_{III} concrete to reduce the anti-shrinkage effect of the most obvious.

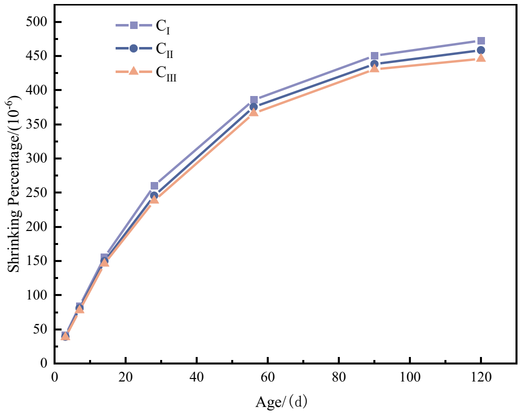


Fig. 3. Shrinkage development pattern of concrete with different proportions

3.3 Analysis of Concrete Resistance to Chloride Ion Permeability

Figure 4 Showing a picture of the concrete electrical flux test. The 28d electric flux test values of concrete with different admixture ratios are shown in Fig. 5, from which it can be seen that the electric flux value of C_{II} concrete is the smallest, followed by that of C_I concrete, and the value of C_{III} concrete is slightly larger than that of C_I, which is consistent with the results of the analysis of the porosity of the concrete, and the fly ash and silica fume slurry can reduce the total porosity and pore volume of the concrete to form a more dense microstructure, which is favorable for the improvement of the anti-permeability performance of the concrete. The internal curing agent will have a certain degree of weakening effect on the impermeability of concrete, mainly because the internal curing agent will increase the overall porosity of concrete, which will increase the permeability of concrete, thus reducing its impermeability. Therefore, the impermeability of C_{III} concrete is slightly worse than that of C_I concrete.

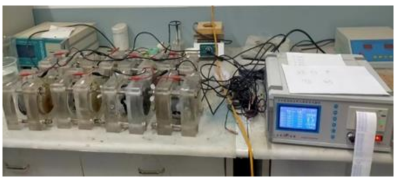


Fig. 4. Impermeability test

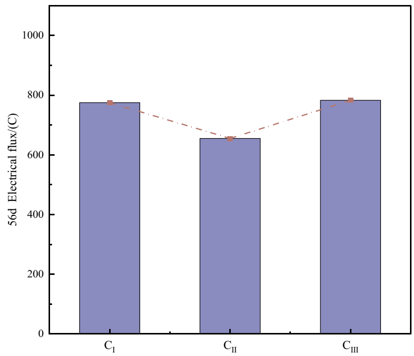
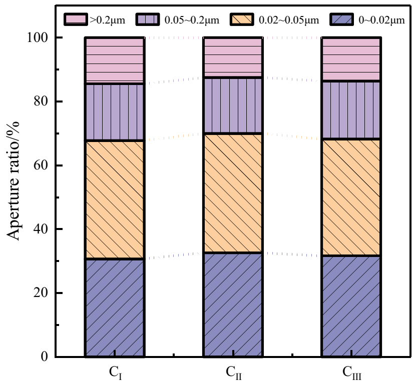


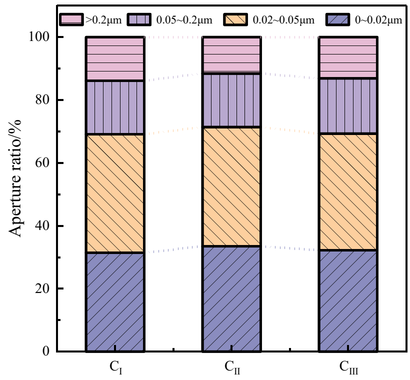
Fig. 5. 56d electric flux values for different mix ratios of concrete

3.4 Analysis of Microscopic Pore Structure Test Results

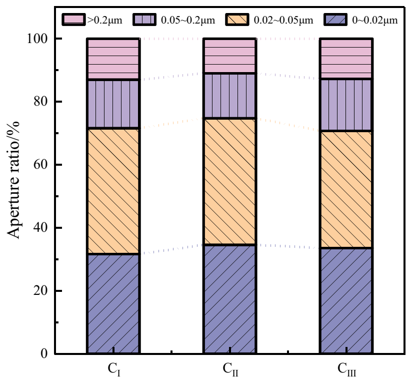
The distribution of three kinds of concrete holes: harmless holes (<0.02μm), less harmful holes (0.02~0.05μm), harmful holes (0.05~0.2μm) and more harmful holes (>0.2μm) were obtained by the NMR microstructure analyzer, among which the harmful holes and more harmful holes have a greater influence on the mechanical properties and durability of the concrete, so this paper focuses on the analysis of these two types of holes.



(a)Percentage of pore size at 7d age



(b)Percentage of pore size at 14d age



(c)Percentage of pore size at 28d age

Fig. 6. Percentage of pore size in each zone of concrete with different age ratios

Figure 6 shows the change rule of the proportion of different pore size distributions of the three kinds of concrete, it can be seen that, in 7d age, the total proportion of harmful pores and more harmful pores of C_{I} concrete is 32.27%, C_{II} concrete is 30.04%, and C_{III} concrete is 31.74%. With the increase of age, the proportion of harmful pores and more harmful pores of the three kinds of concrete gradually decreases, and the proportion of harmless pores and less harmful pores increases. Compared with the age of 7d, at the age of 28d, the ratio of harmful pores and more harmful pores of C_{I}

concrete, C_{II} concrete and C_{III} concrete decreased by 3.84%, 4.77% and 2.49%, respectively. Figure 7 shows the development of the porosity of each concrete at different ages, in which the development of the porosity of C_{II} concrete is optimal, and the reduction of the total pore content is more obvious compared with the other two groups of ratios, while the porosity of C_{III} concrete is the highest, and the ratio of harmful holes and more harmful holes is also slightly higher than that of the other two groups.

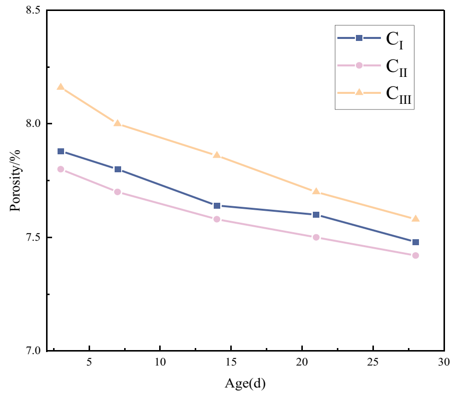
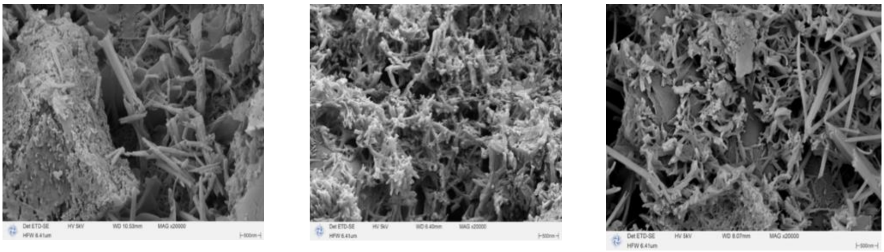


Fig. 7. Porosity development of concrete at different ages

Since the particle size of fly ash is smaller than that of cement, it can effectively fill the pores in the concrete to enhance the densification of the concrete structure. With the increase of curing age, the large pores of the three kinds of concrete are gradually filled and the number of small pores increases, which makes the concrete have a better pore structure. The pore development of C_{II} concrete shows that when the two materials of silica fume slurry and fly ash are mixed together, not only the water loss effect brought by the plateau environment can be slowed down to a certain extent, and the larger the amount of replacement cement is, the more obvious the slowing down effect is. At the same time, the fly ash and silica fume can quickly react with the hydration products of the cement in the secondary reaction to generate the silicate gel. Not only can reduce the relative amount of free $Ca(OH)_2$ in concrete, but also spherical silica fume particles and silicate gel can fill the large pores and cracks inside the concrete, reduce the rate of water loss of the concrete, and reduce the pore size percentage of the harmful pores and polyhazardous pores, so as to make the concrete form a denser microstructure. The distribution of pore sizes of the C_{III} concrete shows that due to the water-holding effect of the internal curing agent, the cement hydration is higher, and the gel within the range of 0~0.02μm range of gel pores and small capillary pores accounted for a higher percentage than that of single-mixed fly ash concrete. Since the shrinkage of concrete is mainly affected by small capillary pores, the shrinkage of C_{III} concrete will also be improved to some extent. However, with the increase of small capillary pores, the content of large capillary pores will also increase accordingly, and the total porosity of the concrete will also increase, which may affect the compressive strength of the concrete to some extent, but by adjusting the content of the internal curing agent can be achieved to improve the shrinkage of the concrete and slightly reduce the strength. Generally, the development of the pore structure of C_{II} and C_{I} concrete is superior to that of concrete C_{III} concrete.

3.5 Concrete Porphology (SEM) Analysis

In order to investigate the influence of different admixture ratios on the hydration process of concrete from a microscopic point of view, the hydration of concrete with different ratios, the type of hydration products and microscopic morphology characteristics were observed by scanning electron microscope test. Figures 8 show the 28d scanning electron microscope pictures of three kinds of concrete, In Fig. 8-(a), it can be seen that there are a large number of flaky calcium hydroxide crystals and needle-like calcium vanadate crystals in C_{I} concrete, and the cementite matrix contains large cracks and pores, which adversely affects the strength of the concrete; from Fig. 8-(b), it can be observed that, compared with the C_{I} concrete, the various hydration products of the C_{II} concrete are connected together into a piece, and the structure of the cracks and pores is effectively optimized, and the calcium hydroxide crystals are almost completely consumed. This indicates that the compound mixing of silica fume slurry and fly ash can make the volcanic ash reaction occur fully, thus generating more reticulated calcium silicate gel, making its microstructure more dense, and the strength of the concrete is increased; Figure 8-(c) shows the scanning electron microscope picture of C_{III} concrete, it can be observed that the content of calcium hydroxide crystals is significantly reduced, but there still exists a small amount of lamellar calcium hydroxide crystals, which indicates that the degree of hydration reaction of the concrete mixed with fly ash and internal curing agent is relatively low compared with that of the concrete mixed with fly ash and silica fume slurry, this is due to the fact that the compatibility, content and so on of the liquid internal curing agent have an important influence on the hydration process and pore structure evolution of the concrete. Meanwhile, C_{III} concrete contains more needle-like Calcovanadium crystals, Calcite can compensate for the early strength of concrete to a certain extent, but it usually exists in the pore structure of concrete, which indicates that shows that the porosity of C_{III} concrete is higher, which is consistent with the results of the test on the compressive strength and porosity of concrete.



(a) 28d SEM plot of C_{I} concrete

(b) 28d SEM plot of C_{II} concrete

(c) 28d SEM plot of C_{III} concrete

Fig. 8. 28d SEM plot at different ages

3.6 Concrete Physical Analysis

Fig. 9 shows the XRD patterns of C40 concrete with different external admixture ratios at the age of 28 d under the environmental conditions of low temperature, low air pressure and low humidity in the plateau region, and the main substances are SiO_2, $Ca(OH)_2$, C_3S, C_2S, $(MgAl)_3(SiAl)_2O_5(OH)_4$. The hydration degree of the concrete under the three ratios was analyzed, and after the addition of the external admixtures, compared with the other two ratios, the $Ca(OH)_2$ diffraction peak intensity of C_{II} concrete was the lowest, which indicated that the incorporated fly ash and silica fume slurry reacted with $Ca(OH)_2$ to consume part of the calcium hydroxide and promote the secondary hydration of the cement, which would result in denser concrete with lower porosity. Meanwhile, the generated silicate gel with high coagulability and high viscosity effectively fills the fine pores and cracks in the concrete, reduces the pore size percentage of harmful pores and multi-harmful pores, and improves the impermeability and crack resistance of the concrete. At the same time, the generated silicate gel helps to cement the aggregate and cement in the concrete together, improving the homogeneity and stability of the concrete, comparing the intensity of $Ca(OH)_2$ diffraction peaks of C_{III} and C_I concrete, the $Ca(OH)_2$ generated by the hydration reaction of concrete decreases when the internal curing agent is added, which is corroborated with the concrete morphology obtained in the above SEM tests.

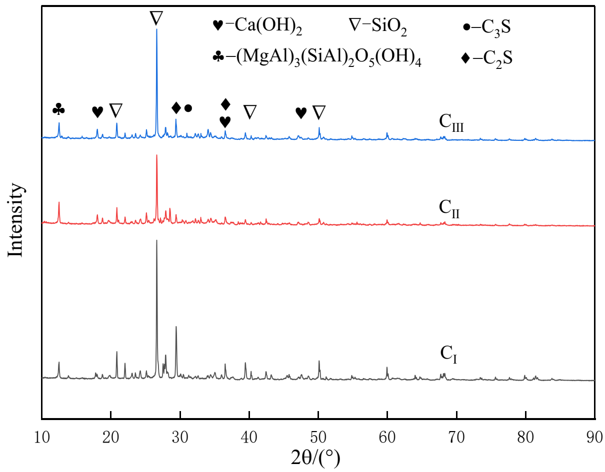


Fig. 9. XRD pattern of concrete specimens

4 Analysis of Concrete Properties Preferences

Comprehensively, it can be seen that the three kinds of concrete mixing ratios show different development in terms of microscopic pore structure, macroscopic mechanical properties, shrinkage properties and seepage resistance, in order to be able to screen out the concrete external admixture and mixing method that has the highest degree of matching with the field service environment under the research situation of this paper, combined with the foregoing test indexes, this paper adopts entropy power method to carry out the preference analysis.

Entropy weight method is a multi-objective decision-making method, which helps decision makers to make effective decisions by calculating the importance weight of each factor in the decision. Compared with other subjective weighting models, the entropy weighting method can avoid the interference of human factors on the weights of indicators, thus improving the objectivity of the comprehensive evaluation results[8]. In the process of assigning weights to each indicator, if the gap between the values of an indicator is large, it is considered that the indicator carries a large amount of information, and its corresponding entropy value is small, indicating that the weight of the indicator is large. When the values of an indicator are all equal, the indicator does not carry any valid information, the entropy value is the maximum, and at this time, the value is considered to be eliminated from the evaluation indicators. In practical application, effective indicators can be initially screened according to the degree of difference between the values of the evaluation indicators, and then the entropy weight of each indicator is calculated, and then the weight of each indicator is obtained.

In this paper, five evaluation indicators of porosity, harmful pore+multi-harmful pore content, compressive strength, shrinkage, and permeability are weighted and scored, and the calculation process is as follows[9]:

(1) Data standardization. Beneficial indicators are those that have a higher value, which are positive indicators, and can be calculated using Equation 1; cost-type indicators are the indicators whose value is the smaller the better, negative-type indicators, which can be calculated using Equation 2. The calculation results are shown in Table 2.

$$m_{ij} = \frac{x_{ij} - min\left(x_j\right)}{max\left(x_j\right) - min\left(x_j\right)} \tag{1}$$

$$m_{ij} = \frac{max\left(x_j\right) - x_{ij}}{max\left(x_j\right) - min\left(x_j\right)} \tag{2}$$

Where, i=1, 2, 3, referring to three samples of proportioned concrete; j=1, 2, ... , 5; referring to the five evaluation indicators; $min\left(x_j\right), max\left(x_j\right)$ denote the minimum and maximum values under the indicator, respectively.

Table 2. Normalized values for each indicator

Sample No	Porosity	Harmful pore+ multi-harmful pore content	Compressive strength	Shrinkage	Permeability
C_I	0.625	0.206	0.460	0.000	0.063
C_{II}	1.000	1.000	1.000	0.674	1.000
C_{III}	0.000	0.000	0.000	1.000	0.000

(2) Specific gravity calculation. Calculate the proportion of sample i among all samples in the indicator, using formula 3, p_{ij} indicates the numerical proportion of the ith sample in the jth indicator, and the results are shown in Table 3.

$$p_{ij} = \frac{m_{ij}}{\sum_{i=1}^{3} m_{ij}} \tag{3}$$

Table 3. Sample weights under each indicator

Sample No	Porosity	Harmful pore+ multi-harmful pore content	Compressive strength	Shrinkage	Permeability
C_{I}	0.385	0.171	0.315	0.000	0.059
C_{II}	0.615	0.829	0.685	0.403	0.941
C_{III}	0.000	0.000	0.000	0.597	0.000

(3) Information entropy of each index and information entropy calculation weights. The entropy value is calculated by using equation 4, in which p_{ij} can be obtained by equation 3; k can be calculated by k=1/ln n, in which n is the number of evaluation objects, and under the research conditions of this paper, n=3; the entropy value obtained by subtracting the calculation by 1 is the value of redundancy; and the weight is calculated by using equation 5. The results of entropy value, redundancy and weight calculation are shown in Table 4.

$$E_j = -k\sum_{i=1}^{3} p_{ij} \ln p_{ij} \tag{4}$$

$$W_j = \frac{1-E_j}{\sum_{j=1}^{5}\left(1-E_j\right)} \tag{5}$$

Table 4. Entropy value redundancy and weight of indicators

Sample No	Porosity	Harmful pore+ multi-harmful pore content	Compressive strength	Shrinkage	Permeability
Entropy	0.607	0.417	0.568	0.614	0.205
Redundancy	0.393	0.583	0.432	0.386	0.795
Weights	0.152	0.225	0.167	0.149	0.307

(4) Comprehensive score: According to the data in Table 4, the composite score of each sample was calculated as equation 6, and the results are shown in Table 5.

$$Z_i = \sum_{j=1}^{5} W_j \times P_{ij} \tag{6}$$

Table 5. Composite scores for each sample

Sample No	C_{I}	C_{II}	C_{III}
score	0.237	0.951	0.149

5 Conclusion

Based on the plateau environment, this paper investigates the changing law of concrete properties under three ratios of 30% fly ash, 30% fly ash + 5% silica fume slurry and 30% fly ash + internal curing agent, and obtains the following conclusions:

(1) Concrete morphology, physical phase composition, pore structure and electrical flux data show that 30% fly ash + 5% silica fume mortar hydration is more complete, the secondary hydration reaction generates more C-S-H gel, filling the harmful pores and more harmful pores inside the concrete, increasing the percentage of harmless pores and less harmful pores, and making the pore rate lower, so as to enhance the concrete seepage resistance performance.

(2) Concrete specimen compressive strength data show that before 7d age, mixed with internal curing agent concrete has high compressive strength, after 7d, mixed with silica fume slurry concrete compressive strength development faster, compared with the single mixed with 30% fly ash, mixed with 5% silica fume slurry concrete 28d compressive strength increased by 5.4%, 56d compressive strength increased by 3.3%; and mixed with internal curing agent concrete 28d compressive strength decreased by 4.6%, 56d compressive strength decreased by 4.4%.

(3) The shrinkage test of concrete showed that compared with 30% fly ash alone, the 56d shrinkage strain of concrete with 5% silica fume mortar and internal curing agent decreased by 2.7% and 5.6%, respectively.

(4) The entropy weighting method was used to evaluate the performance of the concrete in three different ratios, and 30% fly ash + 5% silica fume mortar was the best ratio, so it is recommended to use fly ash and silica fume mortar in mass concrete in plateau environment to improve the service life of concrete.

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