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Research Article

Concrete Interface Feature Extraction and Stability Analysis Based on PCA Model

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With the rise of concrete pumping construction technology, high-mobility concrete has been more and more widely used. However, high fluidity concrete is prepared with high sand ratio and small stones, which weakens the volume stability of aggregate as a skeleton. Therefore, instability often appears in the practical application of large concrete. At present, the research on the stability of concrete interface feature extraction is still relatively scarce. In this paper, through a large number of experiments, the law of the main performance of concrete is systematically studied, and the characteristics of concrete interface are extracted using the principal component analysis (PCA) model. On this basis, the influence of different factors on the stability of concrete is studied, especially the compressive strength, volume stability, and durability of concrete. The experimental results will have a good reference value and far-reaching significance for improving the application status of high fluidity concrete.

1. Introduction

With the gradual improvement of the urbanization in China, the construction industry has made great achievements, but at the same time, the environment faced by the construction of engineering projects and the construction materials that can be used and needed has also changed a lot [1]. According to the Blue Book on China's Urbanization, China's urbanization rate will rise to more than 70 percent by 2030, and the number of urban residents will increase by more than 200 million, as the Chinese population increasingly gathers in big cities. With the establishment and practice of the concept that clear waters and green mountains are as good as mountains of gold and silver, and the promotion of comprehensive resource conservation and recycling policies, relevant policies are constantly improved and updated, the management policy of urban construction land is becoming more and more strict, and the urban construction land is increasingly tense [2]. Therefore, the construction of high-rise residential and commercial complex has become the trend of urban construction and development [3, 4].

China began to use concrete pumps in engineering in the 1950s. In the early stage of reform and opening, concrete pumps began to be applied on a large scale in the construction of Shanghai Baoshan Iron and Steel General Works and gradually popularized in high-rise buildings. Figure 1 shows the concrete surface and the damaged concrete. Many high-performance concretes have been developed by many research institutes based on high fluidity concrete. For example, the concrete with high strength and high fluidity [5, 6] can satisfy the construction of some long-span bridges, undersea tunnels, and other structures. Active powder concrete with high fluidity is characterized by high strength, good durability, and high fluidity, which can better satisfy the construction of deep foundation pit and deep-sea alpine area. Color flow concrete used for decoration engineering can better meet the needs of color diversity, having a good overall appearance effect, simple construction process, short construction period, fade resistance, and less environmental pollution [7].

Although the large fluidity of concrete, conducive to pumping and pouring, there are still various problems in the

Concrete interface Damaged concrete

Figure 1: The concrete surface and the damaged concrete.

engineering application, such as the current industrial buildings and civil buildings used in the ready-mixed concrete generally required to slump in more than 180 mm, but causing shrinkage and cracking phenomenon. The study shows that there are many factors causing shrinkage and cracking of concrete, such as low relative coarse aggregate consumption, high cement consumption, poor quality of raw materials, and poor construction control [8, 9].

Concrete can be regarded as a three-phase composite material composed of coarse aggregate, hardened cement mortar, and the interface transition zone between the two. The macroscopic mechanical properties of concrete are greatly influenced by the microstructure, and its failure process often centers around the development of crack germination generated by defects or internal weak areas. The problem of the microstructure scale is unavoidable in the study of the mechanical stability characteristics of concrete [10, 11]. As the lightweight aggregate of pervious concrete, ceramsite's spherical shape and excellent water permeability are beneficial to the study of pervious concrete structure. Ceramsite is composed of clay, mudstone, shale, coal gangue, fly ash, and so on as the main material, after processing granulation or pulverized into a ball, burning and swelling of an artificial light aggregate. The preparation of ordinary concrete needs to consume cement, coarse aggregate, and fine aggregate and a large number of native materials, in the process of continuous mining and use. These natural resources will always be exhausted one day, if reasonable and effective measures are not adopted to analyze and study the characteristics of concrete.

Since the birth of concrete, scientists have been committed to the research and improvement of material properties, using a variety of experimental means and theoretical methods to study the physical and mechanical properties of concrete, and the construction of sponge city is to apply the permeability of concrete [12]. There are many factors affecting the permeability of concrete, such as the porosity of concrete, concrete own characteristics, and fluid properties. In view of the importance of the permeability of concrete, scientists at home and abroad have been committed to the study and improvement of the permeability of concrete, especially in the correlation between permeability and porosity formed norms and guidelines.

However, considering porosity alone does not guarantee durability of concrete. This is because, on the one hand, concrete with high porosity can ensure its permeability, but cannot meet the strength requirements under load. On the other hand, when the concrete structure in local porosity is higher or lower than the total porosity, local high porosity of the part can be easily squeezed damage energy absorption area around, and the partial concrete is easy to pass around energy surrounding concrete damage [13]. Therefore, scientific workers began to study the physical and mechanical properties of concrete with a different porosity. Through static uniaxial compression experiments and numerical simulation of concrete with different porosity, the influence of porosity on concrete strength, elastic modulus, Poisson's ratio, and other physical and mechanical parameters were revealed. However, with the further study of concrete, many scholars found that the above experiments can explain the mechanical change law of concrete with a different porosity. Therefore, the research must be combined with the actual situation that is to consider the load of concrete during road passage.

The main function of concrete road is to ensure the smooth transportation to the maximum extent, which requires that the overall structure cannot be destroyed in a large area in the case of roughly equal concrete porosity, so as to ensure the durability of the overall structure. Different road environments have different requirements for mechanical properties of porous concrete, especially when concrete is subjected to cyclic loads, and the relevant conclusions of concrete obtained through static compression tests are no longer applicable. Under the action of cyclic load, concrete internal micro-cracks will continue to extend, with the increase of the number of cycles, crack expansion speed up until the crack through and lead to the destruction of concrete structure. In addition, during cyclic loading for concrete with a different porosity, the elastic deformation energy accumulation is the main source of energy release [14, 15].

Analysis by above discussions, nowadays, of concrete, is mainly concentrated on the preparation and performance research; research on the characteristics and stability of the concrete structure is gradually expanded. In order to get a comprehensive understanding of the concrete material, fill the blank of the science and feature extraction and stability of permeable concrete analysis of the research is necessary and meaningful. Under the guidance of systematic science methodology, a comprehensive research approach and method combining indoor experiment, statistical analysis, theoretical analysis, and computer simulation are adopted to study the interface characteristics and overall stability of concrete.

2. Related Work

How to deal with and improve the volume stability is particularly important for the application of concrete. The volume stability of coagulation includes shrinkage and expansion. The shrinkage presented as the volume decrease is resulting from internal condensation and solidification, chemical changes happened in maintaining process in early period, water loss, and temperature changes of both internal and external environment. In the case of poor quality of raw materials, construction process control, and poor construction conditions, the above several shrinkage is more serious. Tensile stress exceeding its corresponding tensile strength resulting from the general shrinking growth of the concrete in some parts of the concrete results in cracking and extending. The ununiformity of the components of concrete leading to different degrees of compression in different parts leads to different general shrinkage volume in each part of the abovementioned five types of shrinkage [16, 17].

According to the internal structure characteristics of concrete, some researchers at home and abroad have studied the mechanical properties of concrete and analyzed the cracking phenomenon of concrete from three different perspectives: mesoscale, micro-scale, and macro-scale. Macroscopic scale refers to the volume characteristic of about a few centimeters, about 3~4 times of coarse aggregate. Mesoscale refers to the relative scale from the molecular scale to the macroscopic scale. In the mesoscale, concrete is regarded as a composite material, composed of stones, hardened cement mortar, and bond parts. Micro-scale refers to the atomic and molecular scale of length; in the microscale, cement slurry is regarded as a kind of calcium hydroxide, calcium silicate hydrate, cement particles without chemical reaction, pore water, and other chemical components. From the analysis of meso-structure, the crack of concrete is mainly caused by the fracture of gravel and the fracture of cement mortar. Strength of mortar part is lower than the cement strength; the aggregate and cement mortar on the interface of cement hydration products of crystallization effect is different. So, the surrounding portion of the gap rate is greater than the other part, this part of the interface is also the most prone to failure deformation of concrete, and often the greater the particle size of aggregate, the interface part of the damage is more serious. The transition interface between aggregate and mortar is the most vulnerable part in concrete.

In terms of the relationship between porosity and compressive strength, a large number of related experiments have been done to study the influence of porosity change on compressive strength, and the relationship between compressive strength and porosity change has been obtained [18]. Domestic research on concrete tends to study the mechanical properties of composite materials and ultra-high-performance concrete. Some scholars achieved the porosity requirements of concrete by controlling the proportion of concrete ingredients or using plastic material filling mode [19]. Research [20] shows that the damage evolution process under the cyclic loading and static loads is different. Domestic scholars on the mechanical properties of cyclic loading concrete are relatively backward, but with the development of civil engineering in recent years, the use of cyclic loading on the mechanical properties of concrete research boom. Reference [21] studied the uniaxial tensile properties of concrete under the action of variable amplitude cyclic load and carried out the uniaxial dynamic tensile test of concrete on 76 dumbbell-shaped specimens with MTS 318 electro-hydraulic servo universal testing machine. The results show that the dynamic strength of concrete mainly depends on the maximum loading rate within each cycle, and the influence of cyclic increase is relatively small.

In meso-mechanics, concrete is considered as a heterogeneous material at the meso-level, and its nonlinear behavior is caused by the weak areas and defects in the complex structure. Crack germination, often around the interface transition zone and internal defects, and aggregate can produce internal force concentration in the process of experiment, and the weak zone around the aggregate will therefore produce tiny crack. But aggregate suppresses the extension of cracks, the increase of concrete strength, and the existence of the residual strength of cement mortar as the main body is the main part of the fracture propagation. After the formation of through cracks, the concrete is damaged. Based on the understanding of the failure process of meso-structure concrete, many scholars have conducted extensive research on the mechanical model and theoretical methods of concrete, which has laid a solid foundation for the subsequent research and application of concrete mesoscopic damage model, which laid a foundation for the future generations to conduct the concrete meso-damage model. Based on the continuous damage theory and statistical theory, reference [22] proposed a simple statistical damage model to reflect the relationship between the redistribution of force inside concrete and the damage evolution. The authors of [23] studied the failure process of concrete materials by combining macro- and micro-methods, and believed that the damage and failure of materials were the result of the joint action of internal defects and weakened strength zones. Therefore, it is very necessary to analyze the mechanical behavior of concrete at the meso-level considering the internal structure of concrete.

The common performance indexes of concrete include porosity, permeability coefficient, and compressive strength. Porosity is divided into closed porosity, semi-closed porosity, and continuous permeability, and the permeability space determines the permeability coefficient of porous concrete. The combination of semi-closed porosity and continuous passage through pores is called effective porosity because semi-closed pores can function as water storage, although not for osmotic purposes. The results of [15] show that the key factors affecting the water permeability coefficient, porosity, and compressive strength of porous concrete are the size of aggregate, grading, and cement-collecting ratio. Under the condition of a certain water-cement ratio, when the cement-collecting ratio decreases and the cement consumption increases, the compressive strength of the specimen increases, but the water permeability of the specimen decreases greatly, and the water-cement ratio has a great influence on the water permeability of permeable concrete. In the mix design of pervious concrete, considering the appropriate amount of fine aggregate under the requirement of permeability coefficient, higher strength and the best dosage can be obtained. The influence of hammer number on the strength and bulk density of concrete was studied by means of layered ramming forming in [24]. The results showed that the strength and bulk density of porous concrete increased gradually according to the mole growth, but when the hammer number reached a certain amount, the strength and bulk density tended to be stable. The reference [25] considered mechanical vibration molding and manual tamping, and the manual tamping block formed better uniformity than the vibration molding machine block, but poor compactness ratio. The mechanical vibration molding test block is tightly packed, but the slurry is easy to deposit at the bottom. The combination of mechanical vibration and manual tamping can achieve the ideal effect of permeability coefficient and compressive strength. The possibility of recycled aggregate concrete being used as structural material was studied in [26]. The study found that, in the case of no transverse reinforcement, the impact of the shear strength of recycled concrete beams depended on the replacement rate of recycled coarse aggregate, and the shear strength of recycled aggregate was not different from that of limestone and standard natural aggregate.

In practical engineering, compared with ordinary flowing concrete, although the flow performance of concrete mixture meets the requirements, the stability of concrete becomes worse, it is easy to shrink and crack, and the later strength cannot meet the requirements. At present, there are few researches on the volumetric stability of concrete with high fluidity. It is of great significance to study and reveal the influencing factors of concrete stability, which can better promote the application of concrete. Therefore, this paper firstly extracts the characteristics of concrete and, on this basis, reveals the influencing factors of concrete stability. Based on the above discussions, the main contributions of this paper are listed as below:

(1) PCA model is applied to feature extraction and stability analysis of coagulation interface for the first time.

(2) The research of this paper not only has strong theoretical significance but also has a certain practical application prospect.

3. The Proposed Cold Chain Material Packaging Optimization Design Method

3.1. Principal Component Analysis Model. Principal component analysis (PCA) [27] is the most common and representative multivariate statistical method, which is widely used in fault detection. It converts the original variables into new unrelated variables through the maximum variance criterion. The new variables with larger variances are called the principal components and can retain the information in the original data as much as possible, while the variables with smaller variances are the projections of the original data in the residual space. Therefore, PCA decomposes the original data into master subspace and residual subspace, and establishes statistical indicators in the two subspaces, respectively, for fault detection. The specific mathematical principles are as follows:

$$\mathbf{X} = \sum_{i=1}^{m} \mathbf{t}_i \mathbf{p}_i^T = \mathbf{T}\mathbf{P}^T + \mathbf{E}, \tag{1}$$

where $\mathbf{t}_i$ and $\mathbf{p}_i$ are the ith principal component and the corresponding load vector, respectively, **P** and **T** are the load matrix and score matrix of the master subspace, respectively, **E** represents the residual matrix, and K represents the number of retained principal components, which is usually determined by the cumulative percent variance (CPV) principle for new real-time measurement data set X. The following two statistics (also called square prediction error, SPE) are often used to monitor the variation and correlation of principal component subspace (PCS) and residual subspace (RS), respectively.

$$\begin{aligned} T^2 &= \mathbf{x}^T \mathbf{P} \mathbf{\Lambda}^{-1} \mathbf{P}^T \mathbf{x}, \\ Q &= \mathbf{x}^T \left(\mathbf{I} - \mathbf{P}\mathbf{P}^T \right) \mathbf{x}, \end{aligned} \tag{2}$$

where Λ is the covariance matrix of T, and the following control limits are used to determine whether the monitored process is running under normal conditions.

$$\begin{aligned} T_{\lim}^2 &\leq \frac{d(n-1)}{n-k} F_{k,(n-k),\rho}, \\ Q_\rho &\leq g\chi_{h,\rho}^2; \quad g = \frac{v}{2a}, \; h = \frac{2a^2}{v}. \end{aligned} \tag{3}$$

Among them, $F_{k,(n-k),\rho}$ is the F distribution of degrees of freedom k and n-k with confidence ρ. a and v are the mean and variance estimated from the Q statistic, respectively.

3.2. Kernel Principal Component Analysis. PCA is inadequate in dealing with nonlinear data. Kernel PCA (KPCA) is a nonlinear extension of PCA algorithm, which can mine the nonlinear information hidden in data samples and has better practicability. KPCA algorithm can map monitoring data to high-dimensional kernel space through kernel mapping and transform the data into a new set of linearly independent representations of each dimension by determining the orthogonal transformation of a coordinate system. In the new coordinate system, the variance of the transformed data is maximized along the new coordinate axis, so that the hidden features of the data can be extracted.

The kernel function realizes the mapping from the original space point to the high-dimensional space through mapping, and the data in the feature space obtained by this mapping are de-mean, so the covariance matrix in the feature space is

$$\mathbf{C}^{\Theta} = \frac{1}{N}\sum_{j=1}^{N}\phi(\mathbf{x}_j)\phi(\mathbf{x}_j)^T. \tag{4}$$

The eigenvalues λ and eigenvectors v satisfy

$$\mathbf{C}^{\Theta}\mathbf{v} = \lambda\mathbf{v}. \tag{5}$$

There are coefficients α_i, such that

$$\mathbf{v} = \sum_{i=1}^{N}\boldsymbol{\alpha}_i\phi(\mathbf{x}_i). \tag{6}$$

Substitute into equation (5) and multiply both sides of equation (5) with $\phi(\mathbf{x}_k)$

$$\lambda\left(\phi(\mathbf{X}_k)\left(\sum_{i=1}^{N}\alpha_i\phi(\mathbf{X}_i)\right)\right) = \phi(\mathbf{X}_k)\mathbf{C}^{\Theta}\left(\sum_{i=1}^{N}\alpha_i\phi(\mathbf{X}_i)\right). \tag{7}$$

Equation (7) can be simplified as

$$N\lambda\boldsymbol{\alpha} = K\boldsymbol{\alpha}, \tag{8}$$

where α is the eigenvector of the kernel matrix K. In actual situations, K needs to be centralized before principal component analysis:

$$\begin{aligned}\overline{K}_{ij} &= \left(\phi(\mathbf{x}_i) - \frac{\sum_{m=1}^{N}\phi(\mathbf{x}_m)}{N}\right)\left(\phi(\mathbf{x}_j) - \frac{\sum_{n=1}^{N}\phi(\mathbf{x}_n)}{N}\right)^T \\ &= (\mathbf{K} - 1_N\mathbf{K} - \mathbf{K}1_N + 1_N\mathbf{K}1_N)_{ij},\end{aligned} \tag{9}$$

where 1_N is the $N * N$ matrix where each element is $1/N$ and N is the dimension of K.

By combining equations (6) and (8), the eigenvector of the covariance matrix can be obtained from the eigenvector $\boldsymbol{\alpha}$ of the matrix K.

According to formula (10), the first P eigenvalues are selected to determine the number of principal components:

$$\frac{\sum_{k=1}^{p}\lambda_k}{\sum_{k=1}^{N}\lambda_k} > 85\%. \tag{10}$$

For the new observation sample X_{new}, its principal component space score vector can be expressed as

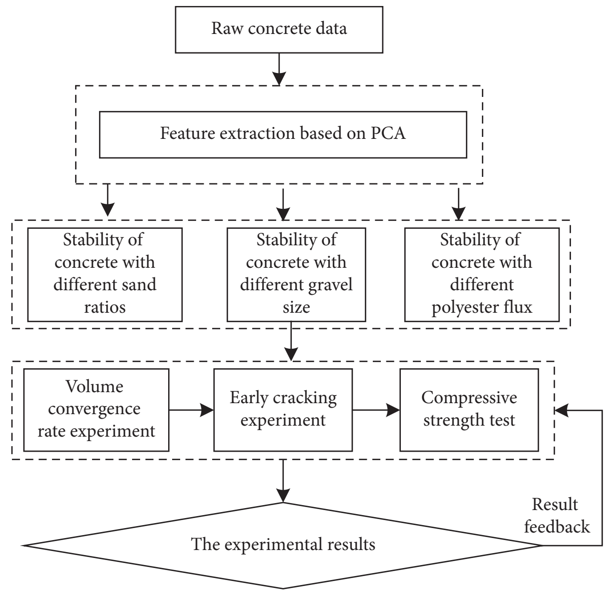


Figure 2: The overall process of the proposed method.

$$\begin{aligned}\mathbf{t}_{\text{new}} &= \left[t_{\text{new},1}, t_{\text{new},2}, \ldots, t_{\text{new},p}\right]^T, \\ t_{\text{new},l} &= v_l\overline{\phi}(\mathbf{x}_{\text{new}}) = \sum_{j=1}^{N}\alpha_j^l\left(\overline{\phi}(\mathbf{x}_j)\overline{\phi}(\mathbf{x}_{\text{new}})\right).\end{aligned} \tag{11}$$

Among them, $L = 1, 2, \ldots, p$, $\overline{\phi}(\mathbf{x}_j)$ is the centralized feature vector.

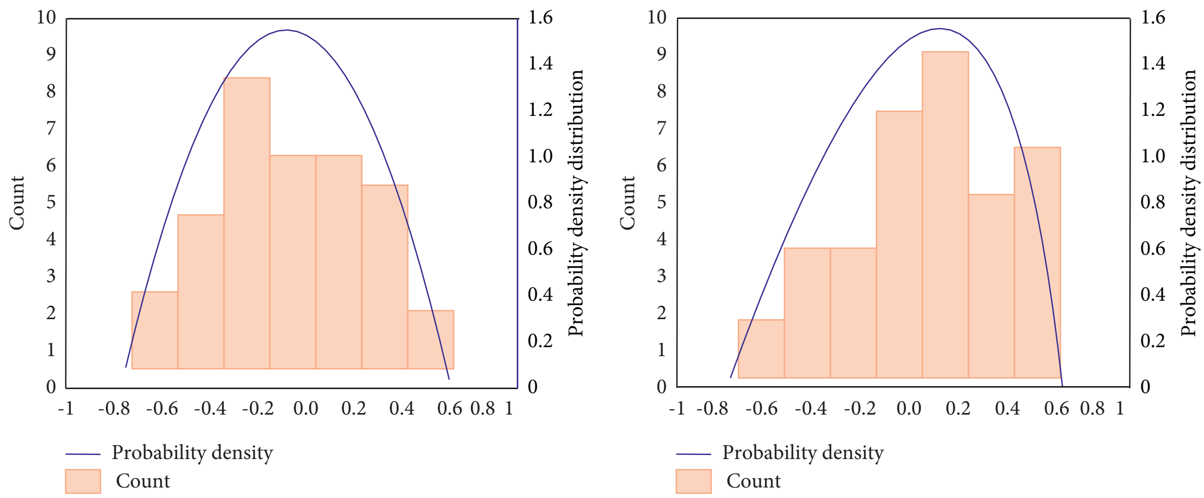
Based on the above discussions, the concrete interface feature extraction and stability analysis model proposed in this work is shown in Figure 2.

4. Experimental Results and Analysis

4.1. Experimental Data Collection and Introduction. Before numerical simulation, the macroscopic mechanical parameters of concrete should be measured. The composite material is composed of cement mortar and interface transition zone. The mechanical parameters of each material need to be tested in laboratory, which lays a foundation for the subsequent study of mechanical parameters of concrete and the establishment of numerical model.

In this test, gravel from a quarry in the suburbs of a city was selected, with hard texture and rough surface, and particle sizes of 5~40 mm, 5~31.5 mm, and 5~20 mm, respectively. The content of needlelike particles met the standard requirements, the water content was 0.18%, and the apparent density was 2690 kg/m.

4.2. Concrete Interface Feature Extraction. It is confirmed that most dynamic mechanical properties of damaged concrete are more discreteness than those of standard concrete due to the change of external construction environment. In addition, different from the statistical analysis of static mechanical properties, concrete feature analysis is the primary difficult problem under dynamic conditions, so PCA model should be used to extract and analyze the surface



(a) (b)

Figure 3: The distribution of dynamic performance characteristics of concrete: (a) dynamic compressive strength; (b) toughness.

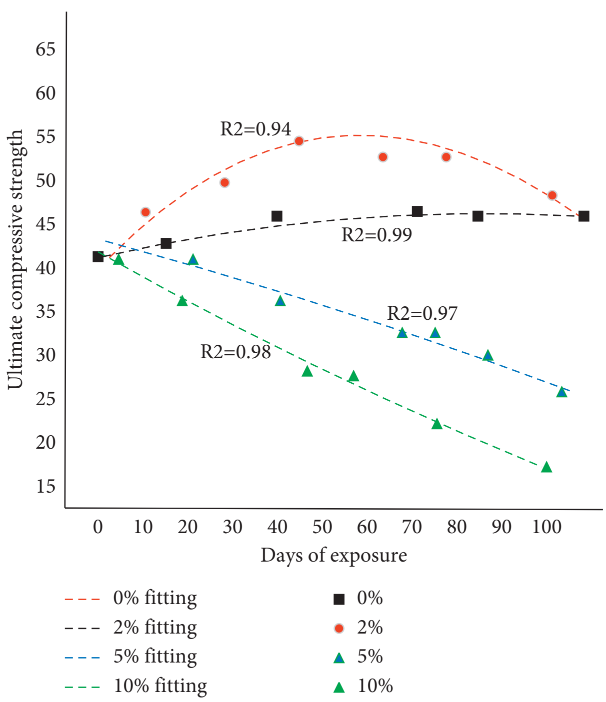


Figure 4: Change and fitting curve of peak strength of concrete under different solution concentrations.

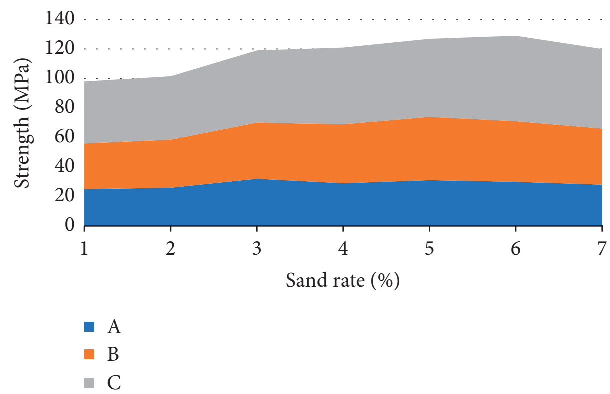


Figure 5: Effect of sand ratio on compressive strength of high fluidity concrete.

features of concrete. In order to further study the statistical characteristics of dynamic mechanical properties of concrete, the normalized residual histogram of features extracted from PCA model is presented in Figure 3.

It can be seen from the figure that the standardized residual strength (left) and standardized residual toughness (right) of concrete with PCA feature basically show the characteristics of normal distribution, which indicates that the concrete features extracted based on PCA model are reasonable and can reflect the intrinsic structural properties of concrete to the maximum extent. It also provides convenience for the follow-up stability analysis of concrete.

4.3. Concrete Interface Stability Analysis. To further analyze the stability of concrete, Figure 4 shows the peak strength of shotcrete specimens soaked in different solutions. The peak strength of the specimens soaked in water shows a trend of rapid growth in 70 days, while the peak strength keeps a slow growth until 100 days after that. For shotcrete specimens soaked in low concentration sulfate solution, the peak strength increases rapidly at the initial stage of 70 days and then decreases rapidly at the turning point of 70 days. This is because chemical corrosion products filled the micro-cracks of shotcrete specimens, which improved the compactness of specimens and caused the strength to rise. However, when excessive chemical corrosion products lead to the damage of the specimen, the strength of the damaged specimen decreases obviously, which is reflected in the reduction of peak strength. It is generally believed that when the concentration of sulfate solution rises, the peak strength changes mainly because the turning point of strength curve moves forward; that is to say, the peak strength turns at an earlier soaking time. Microcrack expansion leads to damage of shotcrete specimens, so the peak strength of specimens does not rise,

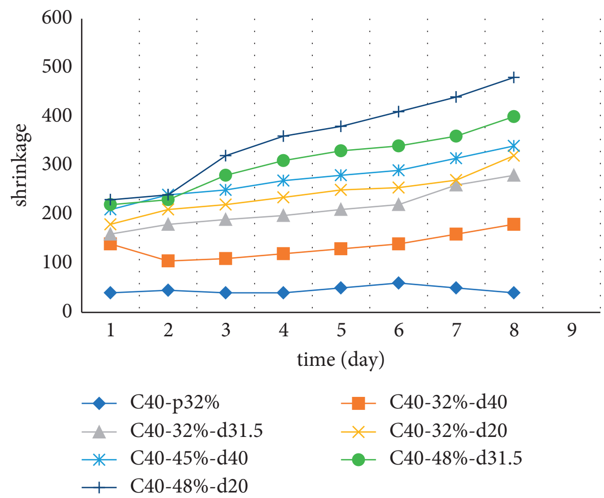


Figure 6: Influence of maximum gravel size on shrinkage of concrete with flow.

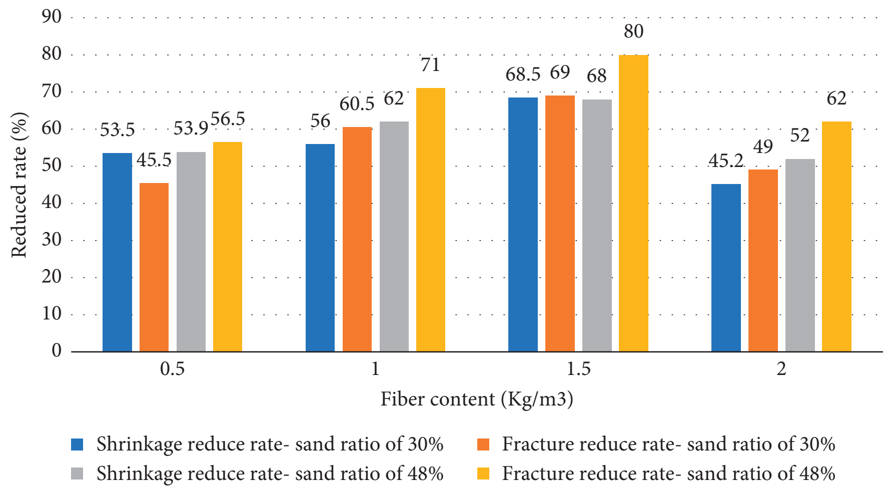


Figure 7: Comparison of volume shrinkage reduction rate, fracture area, and reduction rate.

which is also in line with the characteristics of rapid and violent destruction of physical sulfate corrosion.

According to the similarity coefficient of the fitting curve, the peak strength of specimens immersed in pure water can achieve a good fitting degree by linear fitting or quadratic function fitting (the similarity coefficient $R2$ exceeds 0.9). However, the peak strength of low concentration sulfate solution corrosion specimens can only be fitted as a quadratic function. For the sample group immersed in 5% and 10% solution concentration, it is more appropriate to fit the change of peak strength by linear function.

Sand rate mainly affects the compressive strength of concrete by changing the voidage, surface area, and density of concrete. When the sand rate is too small, the total surface area of coarse and fine aggregate is relatively small, the gap formed is larger, and the concrete strength is low. When the sand ratio is too large, the total surface area of coarse and fine aggregate is larger, the thickness of cement slurry wrapped on the aggregate surface is thinner, and the bond between coarse and fine aggregate is weakened.

It can be seen from Figure 5 that the compressive strength increases first and then decreases with the increase of sand ratio, and there is an optimal sand ratio that maximizes the compressive strength of high-mobility concrete. The compressive strength of the test design strength grades C50(A), C40(B), and C30(C) reached the maximum value when the sand ratio was 3%, 5%, and 6%, respectively, where C50(A), C40(B), and C30(C) are the test numbers.

Under the condition of a certain coarse aggregate mass, with the decrease of the maximum stone particle size, the stone skeleton is loose, and the inhibition of stone skeleton on concrete volume shrinkage is weakened. In addition, Figure 6 shows the influence of maximum gravel size on shrinkage of concrete with flow. As can be seen from Figure 6, with the decrease of gravel particle size, the inhibiting effect of gravel on mortar shrinkage decreases continuously, and the stability of concrete deteriorates. When the maximum stone particle size is the same, the volume shrinkage rate of concrete increases greatly.

Polyester fiber has obvious inhibition effect on concrete volume shrinkage. When the fiber content is 0.5 kg/m^3, 1 kg/m^3, 1.25 kg/m^3, and 2 kg/m^3, the concrete shrinkage rate with sand ratio of 30% at 28 days of age decreases by 53.5%, 56.0%, 68.5%, and 45.2%, respectively, compared with the control group. Compared with the control group, the concrete shrinkage rate with sand ratio of 48% decreased by 53.9%, 62%, 68%, and 52%, respectively. With the increase of polyester fiber content, the inhibition effect of polyester fiber on concrete volume shrinkage first increases and then decreases. The inhibition effect of polyester fiber on the volume shrinkage of concrete with larger sand ratio is better than that of concrete with smaller sand ratio. The details are given in Figure 7.

5. Conclusions

This paper studies the influence of volume stability and other properties of high fluidity concrete. The workability, compressive strength, volume stability, and durability of concrete with a different sand ratio and gravel diameter were tested.

Based on the PCA model, this paper studies the influence rules of concrete volume stability and other properties, and conducts a lot of tests on concrete workability compressive strength, volume stability, and durability with different sand rates and gravel sizes. It is worth noting that the fine aggregate of concrete prepared in this experiment uses natural sand, but the natural sand resources are increasingly exhausted, so the influence law of mechanical sand with different sand rates on volume stability of concrete can be further studied.

Data Availability

In this paper, through a large number of experiments, the law of the main performance of concrete is systematically studied, and the characteristics of concrete interface are extracted using the principal component analysis (PCA) model. The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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