Experimental Study on Cement Admixed with Volcanic Ash

WANG Jianhui¹, FU Shaojun¹,²

¹Shaanxi Key Laboratory of Safety and Durability of Concrete Structures, Xijing University, Xi’an 710123, Shaanxi China
²School of Civil Engineering Wuhan University, Wuhan 430000, Hubei, China

Abstract: Thirty percent cement is respectively replaced by equal quantity red volcanic ash and gray one which are from Yunnan province. Under the same diffusance, the mortal test block of cement, cement-gray volcanic ash, and cement-red one were produced, respectively. Meanwhile the mortar mechanical properties of volcanic ash admixture and non-admixture were compared. The results show that adding these two kind of volcanic ashes into cement will reduce the strength of cement mortar system to some extent. On the basis of this, the micro-analysis of the three mortal systems is performed. The results indicate the strength decrease of cement mortal system is caused by decrease of hydrated calcium silicate crystal which are produced through hydration reaction, and decrease of crystal space structure due to adding volcanic ash.

1. INTRODUCTION

Cement mineral admixtures include fly coal ash, volcanic ash, silica fume and slag are widely used at home and abroad. In China, 12 provinces have volcanic ash resources and are rich in reserves. Due to the different origins of the volcanic ash materials, their chemical component, mineral composition and physical properties are all different, and the degree of influence on the performance of the cement mortar system is also different. At present, the application of volcanic ash in domestic engineering has not been not widely used. And the use of finely ground volcanic ash as a cement admixture are rarely researched.

With the development of the “One Belt and One Road” development strategy in China, many large-scale projects have emerged. In these large-scale projects, the usage amount of cement mortar and concrete is extremely large, and the huge demand for cement admixtures is also very important. At present, the cement admixture in China's large-scale projects is mainly fly coal ash, and the annual output of fly coal ash is limited, especially in recent years in order to alleviate the pollution of the haze by the atmosphere, the country has limited the amount of coal burning. As a result, the output of fly coal ash has declined, and the contradiction between supply and demand for fly coal ash has gradually become prominent. Therefore, the research work on the replacement of fly coal ash in the cement mortar system is of great significance to the construction of the “One Belt and One Road” in China. The volcanic ash from a volcanic ash field in Yunnan is relatively economical in raw material prices, transportation fees, and processing costs. In addition, the use of volcanic ash as a cement admixture for large-scale projects not only helps alleviate the current shortage of fly coal ash resources, but also contributes to the promotion of atmospheric environmental protection in China.

In this paper, the volcanic ash in Yunnan is added to the cement mortar system with 30% of the amount under the same diffusion degree, and the three systems of cement mortar, cement-gray...
volcanic ash mortar and cement-red volcanic ash mortar are respectively carried out. The mechanical properties and microstructure were studied and the results were analyzed.

2. MATERIALS AND EXPERIMENT

2.1 Materials

2.1.1 Cement

The P.O 42.5 cement produced by Shaanxi Qinling Cement Co., Ltd. was used. The physical properties are shown in Table 1.

2.1.2 Volcanic ash

The volcanic ash adopts red and grey natural volcanic ash from a volcanic ash stockyard in Yunnan (replaced with red and gray in the following table respectively). The morphology contour of the two kinds of volcanic ash are shown in Figure 1 and Figure 2. The physical property experiment results are shown in Table 1. After grinding, the chemical compositions of the two volcanic ash were examined. The results showed that the activities of the two volcanic ash were all greater than 70%. The experiment results are shown in Table 2

![Fig.1 Morphology contour of grey volcanic ash](image1)
![Fig.2 Morphology contour of red volcanic ash](image2)

Table 1. Experiment results of physical properties for cement and volcanic ash

| No. | Variety | Density (g/cm³) | Fineness (%) | Specific surface area (m²/kg) |
|-----|---------|----------------|--------------|-----------------------------|
| 1   | Cement  | 3.00           | /            | /                           |
| 2   | Gray    | 2.68           | 2.52         | 528                         |
| 3   | Red     | 2.65           | 2.48         | 470                         |

Table 2. The main chemical constituents of volcanic ash (%)

| Item | SiO₂ /10² | Al₂O₃ /10² | Fe₂O₃ /10² | CaO /10² | SO₃ /10² | MgO /10² | Na₂O /10² | K₂O /10² |
|------|-----------|------------|------------|----------|----------|----------|-----------|----------|
| Red  | 58.1      | 14.55      | 4.81       | 0.241    | 0.0212   | 0.666    | 2.3       | 4.43     |
| Gray | 65.39     | 11.81      | 3.78       | 0.774    | 1.3105   | 0.933    | 0.181     | 2.6      |

2.1.3 Sand

The sand chose to use the ISO standard sand produced by Xiamen ISO Standard Sands Co., Ltd. This
standard sand has passed ISO9001 quality management system and OHSAS occupational health and safety management system certification.

2.2 Experiment scheme
In this experiment, standard rubber sand specimens with a sample size of 40mm x 40mm x 160mm were used to study the cement mortar system, the cement-gray volcanic ash mortar system, and the cement-red volcanic ash mortar system under the standard curing conditions. With the 125mm-135mm diffusion degree, the mechanical properties of the sand system were 3d, 7d, and 28d, respectively. The effect of volcanic ash on the strength of the cement mortar system was studied by comparing the mechanical properties of different systems. The microscopic morphology of each mortar system at different time was observed under a scanning electron microscope (SEM), and the fundamental causes of the influence of the two volcanic ash on the strength of cement mortar were analyzed from the microscopic level.

3. EXPERIMENTAL RESULTS AND MECHANISM ANALYSIS

3.1 Experimental results
Under the condition of fixed diffusion degree, the three kinds of system specimens were maintained under standard curing conditions and maintained for 3d, 7d, and 28d. The compressive strength and flexural strength of each set of specimens were experimented. The results show that the addition of two kinds of volcanic ash will reduce the strength of the cement mortar system to some extent.

![Fig.3 Flexural strength](image)

From Figure 3, we can see that in the condition of fixed diffusion, the flexural strength of the three kinds of rubber sand systems shows an increasing trend with the time, cement mortar system strength is higher than the other two kinds of mortar System strength. The early strength growth rate of the clay sand system mixed with grey volcanic ash mortar and red volcanic ash is relatively close, and the 3d bending strength is 5.0 MPa and 4.5 MPa, which are 71.4% and 64.3% of the cement mortar system respectively; the 7d bending strength is respectively 5.8MPa and 5.2MPa, respectively, 81.7% and 73.2% of the cement mortar system; but the strength of the latter 7d after the latter is significantly higher than the former. At the 28d age when the former strength significantly surpassed the latter, the flexural strength was 6.2MPa and 7.2MPa, respectively, which are 68.1% and 79.1% of the cement mortar system.

From Fig. 4, it can be seen that under the fixed diffusion degree, the compressive strength of the cement mortar system is higher than that of the mortar system after the addition of volcanic ash, and the strength shows an increasing trend in general. The early strength increase rate of the cement mortar system mixed with gray volcanic ash is slightly higher than that of the mortar system with red volcanic ash. The 3d compressive strength is 21.3 MPa and 20.0 MPa, which is 62.5% and 58.7 of the cement mortar system, respectively; 7d compressive strength was 26.6 MPa and 23.8 MPa, which were 74.5% and 66.7% of the cement mortar system, respectively; but after 7 days, the strength of the latter was
significantly higher than the former, and the former slightly exceeded the latter at 28 days of age. The compressive strength was 24.1 MPa and 31.4 MPa, which were 62.6% and 81.6% of the cement mortar system, respectively.

![Compressive strength graph](image)

**Fig.4 Compressive strength**

3.2 **Mechanism analysis**

The strength of the cement mortar system is generally due to the volcanic ash reaction \(^2\) between the active components \(\text{SiO}_2\) and \(\text{Al}_2\text{O}_3\) of the system and the hydration product \(\text{Ca(OH)}_2\) of the cement clinker, respectively. And the quantity of products generated by the volcanic ash reaction. Differences in shape and size also lead to differences in strength.

From the strength analysis results above, it can be seen that the strength changes of the three kinds of systems are similar under the condition of fixed diffusion degree. In order to further reveal the mechanism of their strength changes, they are under the scanning electron microscope (SEM) at 3d, 7d and 28d. The glue sand system was observed and the analysis results are as follows.

![SEM figures](image)

**Fig.5 Each mortar system(3d) and SEM figures**

It can be clearly observed from Fig. 5 that a certain amount of needle-like hydration calcium silicate crystals has appeared at this moment in cement mortar, and these needle-like crystals have been distributed in a spatially stretched manner and have initially formed a simple form with a space skeletal structure; fine fibrous hydrated calcium silicate appeared in the system of gray volcanic ash and red volcanic ash mortar. These crystals adhered to the surface of unhydrated cement and volcanic ash particles, and some flocs appeared. But they have not formed a staggered spatial structure system. The number and shape of crystals in the gray volcanic ash mortar system are superior to those in the red volcanic ash mortar system, and the degree of hydration of the former is also better than that of the latter. So, the intensity is slightly higher.
It can be clearly observed from Fig. 6 that the number of acicular hydration calcium silicate crystals produced in the cement mortar significantly increases, and the crystal size also has a significant increase. These crystals are spatially distributed within the mortar and have certain The lap joints formed a good space skeleton structure; the number of fibrous hydrated calcium silicates that appeared in the gray-filled volcanic ash and red volcanic ash mortar systems also increased significantly, but the structure size was also small, and it was also obvious Seeing that there are still some unhydrated cement and volcanic ash particles, the number and shape of crystals in the grey ash mortar system are significantly better than those in the red-doped ash mortar system, so the strength is still slightly higher at this time.

It can be clearly observed from Fig. 7 that the three types of the sand systems have relatively complete hydration reaction at this time, and there are no obvious unhydrated particles. The hydrated calcium silicate crystals produced in the cement mortar system have a good growth condition. Not only are they dense, but they also have long dimensions. They form a complete and reliable space network skeleton structure; the hydration silicon in the mortar system containing gray volcanic ash The amount of calcium acid is also more, the crystal size has also been increased, but also shows a certain spatial network structure, but the network structure is not complete and is not close enough; the amount of calcium silicate hydrate in the sand system with doped red volcanic ash is more It also shows a spatial network structure with dense structure, but the crystal size is small. Because the skeleton is dense, the strength is slightly higher than that of the system incorporating gray volcanic ash.

Cement has very strong hydraulic properties, whereas siliceous and aluminosilicate materials contained in volcanic ash have only weaker gelling properties, and the volcanic ash mortar system has weaker hydraulic properties, and only weak hydration reactions can occur. Due to the strength of the mortar system, the strength of the mortar system will be reduced after incorporation into the volcanic ash. From the microstructure analysis, in the initial stage, the hydration reaction was not thorough in all the sand rubber systems, and there were fewer hydration reaction products, which could not form a
good spatial structure, so the strength was low; with the age, The active SiO$_2$ and Al$_2$O$_3$ in each system further reacted with the volcanic ash reaction of Ca(OH)$_2$ in the cement stone, resulting in more low-alkali hydrated calcium silicate $^{[3]-[4]}$, so the strength was increased. Although the fineness of volcanic ash used in this experiment was fine and the specific surface area was large, the coarse porous glass body was crushed, the adhesion of glass particles was relieved, the surface characteristics thereof were improved, and the physical activity (such as particle morphology effect and micro-aggregate effect) was improved $^{[5-6]}$, the strength of the mortar system can be increased quickly, but the incorporation of volcanic ash reduces the amount of hydration reaction product hydrated calcium silicate crystals and also weakens the crystals in the mortar system to some extent. The spatial structure leads to a decrease in the strength of the mortar system.

4. CONCLUSION

(1) When gray and red volcanic ash is used as an admixture in Yunnan to replace concrete with a proportion of 30%, the intensity of each age period is reduced compared with the cement mortar system, and the latter is incorporated into the latter. The strength growth trend of the mortar system is relatively stable, and the strength of its subsequent growth is also faster, and the value of the later strength reduction is smaller.

(2) After incorporation of the two types of volcanic ash, the amount of hydrated calcium silicate crystals formed in the hydration reaction in the mortar system has decreased, and the spatial structure of the crystals has also weakened, but the mortar system with red volcanic ash was relatively good at the number and shape of crystals in the later period.

(3) Red volcanic ash can be used in engineering as substitutes to replace part of cement.

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