Study on Stability and Durability of Coal Gangue Used in Runway Base

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Abstract. Coal gangue, as industrial waste generated in the mining process, is rarely used in the construction of domestic airport runways. This paper studies the stability of coal gangue and the durability of cement stabilized coal gangue in combination with the characteristics of navigation airport construction. The coal gangue self-stability test includes: chemical composition, loss on ignition, crushing value and expansion ratio. The durability of cement stabilized coal gangue is mainly based on the freeze-thaw cycle test. The test results show that the sum of the content of coal gangue SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ in the mine is more than 70%, the loss on ignition is less than 15%, the control standard can be achieved, and the expansion ratio is not more than 0.5%. Coal gangue itself has good stability. By comparing the compressive strength values of the standard test pieces before and after 6 freeze-thaw cycles, it is found that the cement-stabilized coal gangue with different cement content has a frost resistance of more than 60%, and the overall frost resistance is good. In addition, considering the load level and safety reserve of the navigable airport, the cement content should be greater than 5%. The above conclusions can provide reference for the application of coal gangue in the field of airport construction.

1. Introduction

In recent years, China's aviation industry has developed rapidly. In addition to the continuous expansion of civil aviation transportation airports, the construction of navigation airports has become a new hot spot. The planning of the navigation airports of various provinces and cities has been put on the agenda. There are already many places to open routes. By 2020, a total of about 600 general-purpose airports will be planned, which is in great demand. The navigable airport mainly provides operational services for helicopters and light fixed-wing aircraft, so the facilities at the navigable airport are often simpler and the load levels are correspondingly lower. The construction standards have not been established in the industry, and it is necessary to study the parameters of various structural layer parameters and materials of the runway. In this study, cement stabilized coal gangue was selected to analyze the requirements of the base material for the navigation airport, and the durability of the cement stabilized coal gangue used for navigating the airport base was studied through relevant tests. As one of the main wastes produced by mining areas, coal gangue has been affecting the surrounding environment since its inception. More than 6 billion tons of coal gangue have been produced since the 1960s, and hundreds of millions of tons of new coal gangue are produced every year [1]. Coal gangue piled up into mountains is easy to spontaneously produce toxic gases, which has a great impact on the environment [2]. At
present, the use of coal gangue as a filling material for civil engineering construction is an important way to solve the waste coal gangue [3]. Although coal gangue has certain commonality as a material, the chemical composition and self-characteristics of coal gangue in different regions are quite different, and it may contain toxic components. When used as a roadbed, it may be damaged by water, or water damage. Therefore, there is no clear norms and standards in the construction of the project to guide the application of coal gangue. There have been many studies on the application of coal gangue at home and abroad, mainly on the road and railway subgrade, and there are few studies on the road base, and there are fewer studies on the use of coal gangue for airport construction.

The French Road and Highway Technology Research Department and the Road and Bridge Center have studied the application of coal gangue in building materials. The results show that coal gangue is easy to compact and has a dry density of 1.81 g.cm³ and good water impermeability [4]. Yuanquan Liu and Yizhong Hu [5] studied the construction process of coal gangue used in roadbed based on soft soil foundation. Zhou Mei [6] et al. stabilized coal gangue with fly ash, used uniform design test and processed data with SPSS technique, and fitted the intensity regression equation. Peifeng Cheng and Huzhu Zhang [7] stabilized the coal gangue produced in a mine in Qitaihe City with cement, studied the relationship between the cement content and the crack resistance of the mixture, and obtained a reasonable interval of cement content. Junyao Liu [8] studied the main mechanical properties of coal gangue mixture applied to the base layer of pavement structure, and proved that coal gangue mixture has high mechanical properties and economic performance for subgrade engineering. Zhao Liu [9] conducted a comparative study on the compressive and flexural strength of a mixture of ash, adding ash and cement, and adding only lime. Fuguo Pei [10] studied the performance of coal gangue using cement stabilized Yangmei No. 1 Mine as the material of pavement base layer, and determined the optimum dosage and construction technology. Dengpan Liu [11] studied the application of coal gangue in urban highway engineering and proposed related construction methods and processes. Coal gangue has been applied in road and railway engineering at home and abroad, and its use effect is good. However, due to its high load level and high safety requirements, the airport is rarely used in domestic field construction. The amount of consumables in the base course of the roadway engineering is large. If the coal gangue can be used as the filling material for the construction of the runway base layer, the coal gangue waste will be solved to a large extent, and at the same time it has good economy, which is also in line with the construction requirements of the navigation airport. The durability test of the base layer in field engineering is an important consideration. Therefore, the durability study of coal gangue mixture can provide a theoretical basis for its application in the navigation airport.

First of all, coal gangue should be considered for the stability of coal gangue when it is used in engineering. The chemical composition, loss on ignition, expansion rate and crushing value of coal gangue are mainly considered in the construction of road and railway subgrade. Coal gangue mainly considers water stability when applied in the road base layer, and the application is not extensive enough. Although coal gangue has commonalities, due to the different production areas, the performance of coal gangue itself is quite different. Coal gangue in different areas needs to be tested separately for practical engineering. The stability and stability of coal gangue can be used as gravel after simple treatment. In addition, the runway base layer in the airport construction needs to have good durability. This study conducted an indoor test on the internal chemical composition of coal gangue in a certain area of Shanxi Province. The effects of different cement content on the residual compressive strength after freeze-thaw cycles were studied, and the durability of cement stabilized coal gangue was evaluated. The theoretical reference basis for the coal gangue used in the mining area for the surrounding airport runway base was provided.

2. Analysis of performance requirements of coal gangue in the base layer of navigable airport pavement

The base layer is the main load-bearing layer of the pavement structure. The current flight area design level of the navigable airport is 2B. According to the relevant requirements of the Specifications for Airport Cement Concrete Pavement Design [12] (MHT5004-2010) and the Specifications for Asphalt
Pavement Design of Civil Airport [13] (MHT5010-2017), the pavement level is 2B, and reference to the application of coal gangue in the road, the base filling material should have sufficient strength and good water stability. This test uses cement stabilized coal gangue. Coal gangue as the base material of the navigation airport, the control parameters can consider the following aspects:

(1) On the one hand, consider the stability requirements of coal gangue used in engineering. The coal gangue with good natural grade is selected, and the gangue with good grading is easy to compact. If the natural grade is poor, it should not be directly used for the pavement base mix. It should be crushed to a certain standard before it can be used as a filler for the cement stabilized macadam base. Coal gangue should consider its stability before use. See Table 1 for the relevant requirements for stability.

| Loss on Ignition | Free Expansion Rate | Disintegration |
|------------------|---------------------|----------------|
| ≤20%             | ≤40%                | ≤30%           |

(2) On the other hand, consider the durability of cement stabilized coal gangue for use in the pavement base. The base layer needs to provide uniform and stable support to the surface concrete slab, so its strength and stability have an important influence on the overall use of the pavement. The base layer is an important part of the pavement structure. Different levels of airport compaction requirements are also different. The navigation airport is designed with a 2B flight zone, and its compaction should reach 96%. The overall strength of the base layer is measured by 7-day unconfined compressive strength. The 7-day unconfined compressive strength of the 2B grade pavement should not be less than 3 MPa. In addition, considering water-stable coal gangue as the base layer of the road surface, it should have good durability. This paper uses the freeze-thaw cycle test as an important indicator to analyze its durability. Analyze whether the residual compressive strength after a certain freeze-thaw cycle meets the bearing capacity requirements of the navigable airport.

3. Experimental results and discussion
The test sample was taken from a mine in Shaanxi with 2 sampling points. Due to the geographical location of coal gangue, the chemical composition will be different, and the mechanical properties and stability will be different. At present, coal gangue is used as a roadbed filler. There is no corresponding standard to standardize various testing indicators, and there is no uniform regulation method. Therefore, this test refers to the relevant standards [14], as well as the reference literature on coal gangue related research, and considers the specific engineering requirements of coal gangue as the base material of airport runway, and analyzes the frost resistance of cement stabilized coal gangue.

3.1. Coal gangue stability test
The test samples were graded and screened, and the gangue grade of the No. 2 sampling point was good, and the remaining three grades were poor. In the test, it was found that due to the large particle size of the coal gangue raw materials, in order to be applied to the compaction of the airport base construction, the coal gangue was firstly crushed. The Cu and Cc values of each sampling point after crushing meet the requirements, and the gradation is within the recommended range of cement stabilized macadam grading, which can be used for base layer filling.

3.1.1. Coal gangue composition and chemical composition experimental. The three most abundant elements in coal gangue are Al, Si, C, and a small amount of Hg, As, Pb, Cr, Cd, Mn and other elements, which will become quartz, mica, limonite under special conditions. Refer to the Roadbed Design Specification (JTG D30-2004) for the total content of SiO2, Al2O3 and Fe2O3 in coal gangue should not be less than 70%. The chemical composition test of coal gangue, the results are shown in Table 2:
Table 2. Ash analysis of coal gangue raw materials.

| Sample Serial Number | \( \text{SiO}_2 \) (%) | \( \text{Al}_2\text{O}_3 \) (%) | \( \text{Fe}_2\text{O}_3 \) (%) | \( \text{TiO}_2 \) (%) | \( \text{CaO} \) (%) | \( \text{MgO} \) (%) | \( \text{K}_2\text{O} \) (%) | \( \text{Na}_2\text{O} \) (%) | \( \text{MnO} \) (%) | \( \text{SO}_3 \) (%) | \( \text{P}_2\text{O}_5 \) (%) |
|----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| No. 1               | 58.02           | 17.30           | 9.74            | 0.86            | 5.14            | 1.02            | 2.54            | 1.40            | 0.15            | 1.89            | 0.09            |
| No. 2               | 58.02           | 17.19           | 10.81           | 0.90            | 4.60            | 0.82            | 2.52            | 1.24            | 0.12            | 2.76            | 0.08            |
| No. 3               | 49.91           | 15.49           | 13.02           | 0.81            | 8.02            | 1.37            | 2.23            | 1.38            | 0.20            | 6.26            | 0.11            |
| No. 4               | 48.62           | 14.86           | 12.9            | 0.74            | 10.88           | 1.25            | 2.12            | 1.44            | 0.18            | 5.82            | 0.10            |

It can be seen from Table 2 that in the statistical analysis of the chemical composition of the four types of coal gangue samples, the composition of \( \text{SiO}_2 \) is the highest, accounting for 48.62%-58.02%; the composition of \( \text{Al}_2\text{O}_3 \) is second, accounting for 14.86%-17.30%; the content of \( \text{Fe}_2\text{O}_3 \) is the third place, accounting for 9.74%-13.02%; the composition of \( \text{CaO} \) is less than the above three, accounting for 4.60%-10.88%. The total contents of \( \text{SiO}_2 \), \( \text{Al}_2\text{O}_3 \) and \( \text{Fe}_2\text{O}_3 \) in the four samples were 85.06%, 86.02%, 78.42% and 76.38%, respectively, and the content of Si and Al is 75.32%, 75.21%, 65.4% and 63.48%, respectively. Therefore, the minerals in the coal gangue are mainly quartz and feldspar, and no sulfide or the like is found to be suitable for the subgrade filler component.

3.1.2. Loss of ignition test. In order to prevent the instability of coal gangue used as a base mixture, materials with a small loss on ignition should be selected. The coal gangue loss in the area is shown in Table 3.

Table 3. Coal gangue burning loss experiment.

| Sampling Point | No. 1 Sampling Point | No. 2 Sampling Point | No. 3 Sampling Point | No. 4 Sampling Point |
|----------------|----------------------|----------------------|----------------------|----------------------|
| Loss on Ignition | 12.8 | 13.4 | 10.6 | 11.1 |

The results in Table 7 show that the loss on ignition of all four sampling points is less than 14%, far less than the 20% control standard.

3.1.3. Expansion test. The amount of coal gangue expansion is also an important indicator of stability. Therefore, the effects of different compaction degrees on the expansion of coal gangue were studied. Determine the height of the test piece before and after immersion, and the formula is as follows:

\[
\delta = \left( \frac{\Delta h}{h_0} \right) \times 100\%
\]

\( \Delta h \) —The height difference before and after the test piece is immersed in water; \( h_0 \) —The height before the test piece is immersed in water; \( \delta \) —the amount of expansion (%)

![Figure 1](image-url)

Figure 1. Relationship between compaction degree and expansion of coal gangue.
It can be seen from Fig. 1 that the swelling amount of coal gangue immersion increases with the increase of compaction degree of coal gangue. Although the amount of expansion increases, the amount of expansion is less than 0.5% when the degree of compaction is 98%. According to the relevant regulations, the compaction of the base layer of the 2B flight zone should reach 96%. Therefore, the amount of expansion is small, far below the engineering requirements.

Through the above test, the self-stability of the coal gangue at the sampling point is good.

3.2. Freeze-thaw cycle test of cement stabilized coal gangue

Freeze-thaw stability is an important measure to measure the durability of the base material. Most of China is located in the northern temperate zone, with seasonal differences in climate change and freezing in winter. The base layer will undergo a process of freezing and thawing, and the strength and stability of the base material will be affected after freezing and thawing, thereby affecting the overall performance of the base layer. Therefore, it is necessary to conduct a freeze-thaw cycle study on the base material.

In this study, the cement stabilized coal gangue was used as the object, and the standard test piece was cured for 28 days and then subjected to freeze-thaw cycle test. Before the freeze-thaw test, wipe off the water on the surface of the test piece and weigh it. When the test is done, firstly, the sample after the water is frozen in a refrigerator at -15 °C for 4 hours, then melted in water at 20±5 °C for 4 hours. This is a freeze-thaw cycle. After 6 freeze-thaw cycles, the test piece after freeze-thaw test is dried to constant weight, the mass is called, and then the compressive strength of the test piece is measured. The ratio of the residual compressive strength after freezing and thawing to the compressive strength before freezing and thawing was used as an index (BDR) for evaluating frost resistance, and the calculation was as shown in Formula 2.

\[
BDR = \left( \frac{\text{Compressive strength before freeze-thaw cycle (MPa)}}{\text{Compressive strength after freeze-thaw cycles (MPa)}} \times 100\% \right)
\]  

(2)

The test results are shown in Table 4 below:

| Cement consumption | Compressive strength before freezing and thawing (Mpa) | Compressive strength after freezing and thawing (Mpa) | BDR (%) |
|--------------------|-------------------------------------------------------|-----------------------------------------------------|--------|
| 4                  | 3.6                                                   | 2.5                                                 | 69     |
| 5                  | 4.4                                                   | 3.0                                                 | 68     |
| 6                  | 4.8                                                   | 3.5                                                 | 73     |

The test results show that the residual compressive strength values of the specimens with cement content of 5% and 6% after 6 freeze-thaw cycles are 3.0 MPa and 3.5 MPa, and the relevant strength requirements can still be achieved. The BDR value did not change significantly when the cement content increased, but the BDR values of the specimens with different cement content after 6 freeze-thaw cycles were above 60%. Cement stabilized coal gangue has better overall frost resistance.

4. Conclusion

After conducting the above indoor tests on coal gangue samples in this area, the following conclusions can be drawn:

The total content of coal gangue SiO2, Al2O3 and Fe2O3 in the mine is more than 70%, the loss on ignition is less than 15%, mainly quartz and feldspar, and the expansion amount is relatively small, and the stability is good.

After grading adjustment, the residual compressive strength of cement stabilized coal gangue with 4% cement content after 6 freeze-thaw cycles is less than 3.0MPa, which does not meet the design load standard of 2B grade airport. The residual compressive strength of cement stabilized coal gangue with
cement content of 5% after 6 freeze-thaw cycles is 3.0Mpa. Although the requirements are met, considering the safety reliability and the late strength loss, there is still risk, so the cement content should be greater than 5%.

In summary, the coal gangue itself has good stability, and the coal gangue water after stable grading with cement has good frost resistance. The cement stabilized coal gangue has good durability and can provide some basis for the construction of the navigation airport base. The navigation airport is required to have good economics when it is required to operate. If coal gangue is used in the construction of a navigable airport, it not only considers the economic requirements, but also consumes waste coal gangue, which plays an important role in environmental protection. Of course, the application of coal gangue in navigation airports requires more research and engineering experiments.

References
[1] Yue Yang. China Resources Comprehensive Utilization, 2014, 32 (6) : 18–22.
[2] Bo Li. Xi'an: Chang'an University, 2013.
[3] Ning Liu, Kaiping Liu, Lijuan Rong, et al. Concrete and Cement Products, 2012 (9) : 74-76.
[4] Y. Z. Sun, J. S. Fan, P. Qin, et al. Environmental Geochemistry and Health, 2009, 31 (1) : 81–89.
[5] Yuanquan Liu, Yizhong Hu. Highway, 2005,(10): 82-85.
[6] Mei Zhou, Shuang Tian, Tao Guo. Silicate Bulletin, 2001, (05):1221-1226.
[7] Peifeng Cheng, Huzhu Zhang, Jingbo Yu. Highway Transportation Technology, 2008, (04):52-56.
[8] Junyao Liu, Chunping Pei, Xiaohui Liu, et al. Journal of Henan Urban Construction College, 2002, 16 (3): 23-26.
[9] Zhao Liu. Heilongjiang Science and Technology Information, 2009 (36): 406.
[10] Fuguo Pei. Shanxi Transportation Science and Technology, 2009 (3): 48-50, 56.
[11] Dengpan Liu, Yu Tian. Anhui Architecture. 2002 (4): 68-69.
[12] MHT5004-2010. Civil Aviation Administration of China. 2010.
[13] MHT5010-2017. Civil Aviation Administration of China. 2017.
[14] JTG E40-2007. Ministry of Communications of the People's Republic of China. 2007.