Analysis of frost resistance of basalt fiber cement solidified aeolian sand subgrade

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Abstract: Through the freeze-thaw cycle test, the damage characteristics of basalt fiber cement solidified aeolian sand with different basalt fiber and cement content, different freeze-thaw cycles and curing age were analyzed. The test results show that with the increase of the basalt fiber content, the damage degree of the basalt fiber cement solidified aeolian sand under the action of freeze-thaw cycle first decreases and then increases, and the damage degree is minimum when the basalt fiber content is 0.5%; The 90-day-old specimens were more resistant to freeze-thaw damage than the 28-day specimens. By establishing the damage model of unconfined compressive strength loss rate and freezing and thawing times of basalt fiber-solidified aeolian sand, it was found that it obeyed the quadratic polynomial change trend, and the fitting accuracy was greater than 0.9. The gray entropy analysis method was used to find that the amount of cement had the greatest influence on the mass loss rate and unconfined compressive strength of basalt fiber-solidified aeolian sand specimens.

1. Introduction
Wind sand is often distributed in desert areas, and is a non-hydropedic, fragmented surface is too fine, less plastic material. Cement as an excellent inorganic gel material, with water formed by the slurry as a condensing agent can effectively wind sand particles wrapped in curing. In the construction of sand-piercing highway, cement-cured wind sand as the road grass and bottom base to replace gravel material, can greatly reduce the cost of highway construction[1]. In the bottom base, cement as a curing material formed by the curing wind accumulation sand after freezing and thawing cycle of the quality loss rate is better than other curing materials[2]. And the gel formed between cement and wind sand particles changes the microstructure of wind sand, thus affecting its deformation and carrying capacity[3]. However, cement curing wind accumulation sand is prone to local damage under load, and because most desert areas of Our country are basically seasonal frozen areas, the liquid expansion and osmosis pressure formed by the freezing and thawing effect is also an important factor leading to the destruction of cement cured wind accumulation sand, improving the antifreeze performance of cement cured wind sand can also further promote the use of wind sand in the project.

Basalt fiber as a "green" industrial material, its excellent corrosion resistance, high and low temperature resistance and good performance of machinery is widely used in the construction industry. The results of basalt fiber show that basalt fiber has good low temperature performance[4]; At the same time, under certain basalt doping conditions can be very good to suppress the deformation of the added...
material damage\(^5\); The study of the temperature-shrinking cracks produced by cement-cured wind-accumulated sand under the action of temperature gradient shows that basalt fiber doping increases in a certain range, and the anti-cracking properties of cement-cured wind-accumulated sand test pieces resist temperature changes become erodable\(^6\).

In summary, combined with the excellent characteristics of basalt fiber and cement-cured wind-accumulated sand, this test is based on cement doping, basalt fiber doping, freezing and thawing times, and the maintenance age is the main research variable, and the test of non-lateral pressure strength and mass loss rate is carried out on the basalt fiber cement-cured wind-accumulated sand test. To study the change law of the test piece's material damage and mass loss; It is proposed to establish a damage model between the loss rate of non-side limit pressure strength and the number of freeze-thaws; The influence of the above main variables on the pressure strength and mass loss rate of the non-side limit is discussed by using gray analysis theory. It provides experimental basis and theoretical support for the use of basalt cement cured wind-accumulated sand in road-based projects in northern China.

2. Raw materials and test methods

2.1 Test raw materials.
The wind sand used in this test was taken from the Kubuzi Desert in Inner Mongolia Autonomous Region, and its particle size was mainly distributed between 0.05mm and 0.25mm, with a relatively single particle size. Cement is a common silicate cement (P.O42.5 grade), the main components are mainly CaO and SiO\(_2\). Short-cut basalt fibers are produced by Zhejiang Shijin Basalt Fiber Co., Ltd., The appearance and physical properties of the fibers are shown in Figures 1 and Table 1. The test water is tap water.

| Length/mm | Diameter/μm | Density/ g/cm\(^3\) | Break strength/MPa | Elastic modulus/GPa | Break elongation/% |
|-----------|------------|----------------------|---------------------|--------------------|-------------------|
| 6         | 17         | 2.63-2.65            | 2800-3200            | 75-90              | 3.1               |

Fig. 1 Short cut basalt fiber

Three cement doping amounts are set in this test\(^7\), 10%, 15% and 20% respectively. Short-cut basalt fibers of 0%, 0.1%, 0.3%, 0.5%, 0.7%, 1.0% and 1.5% were added to each cement doping test.

2.2 The moisture content of the test piece.
Set 10%, 15%, 20%, 25%, 30% of the five moisture content, 10%, 15%, 20% cement doping (internal doping) to prepare the test pieces required for the test and maintenance. After the end of the maintenance of non-side limit pressure test, water content and pressure strength correspondence is shown in Figure 2, water content is less than 20%, the mixture is more viscous, difficult to inject into the test mold, release after the emergence of honeycomb hemp surface. When the moisture content is at 20%, the mixture can be evenly injected into the mold and well formed. When the moisture content exceeds 20%, the mixture appears flowing, difficult to form and low pressure strength after molding. Therefore, the water content is 20%.
2.3 The test method

The test pieces required for the 70.7mm x 70.7mm x 70.7mm cube were molded by the vibration method. The maintenance age of the molded test pieces is 28 and 90d respectively, and the temperature of the maintenance room should be maintained at 20±2℃ and the humidity should be 95%.

The freeze-thaw cycle test was carried out by reference to GB/T 50082-2009 "Standards for long-term performance and durability test methods of ordinary concrete"[9], Combined with the climatic conditions in the north of China, the freezing temperature of the test pieces in the high and low temperature intersecting box is set to -20℃ and the melting temperature is set to 20℃. The frozen-melting cycle reached 1, 2, 3, 4, 5 times the test pieces were taken out for weighing, and the mass loss rate \(W_n\) calculated as 1, \(W_n\) for the n-freeze-thaw cycle after the test piece mass loss rate (%); \(m_0\) is the mass of the test piece before the freeze-thaw cycle (g); \(m_n\) is the mass (g) of the test piece after the n-freeze-thaw cycle.

\[
W_n = \frac{m_0 - m_n}{m_0} \tag{1}
\]

The test of pressure resistance without side limit is carried out according to JTG E51-2009 "Road engineering inorororable combination material stabilization material test procedure"[10]. The instrument uses a fully automatic cement pressure test machine, and the test part loading process is controlled by ise stress, with a load rate of 0.5kN/s.

3. Analysis of the effect of freeze-thawing effect on basalt fiber cement curing wind-accumulated sand.

3.1 Quality loss rate analysis.

Different basalt fibers, cement doping, different maintenance age of basalt fiber cement curing wind accumulation sand test pieces, after different number of frozen and thawing cycles, its mass loss rate change law as shown in Figure 3. Analysis figures a, b, c can be seen: (1) The mass loss rate of the test pieces under the same number of frozen and thawed cycles decreases with the increase of cement doping, and in the case of 20% cement doping, the mass loss rate of all test pieces is less than 1.5%. (2) The mass loss rate and basalt fiber doping showed a trend of decreasing first and increasing later, and the mass loss rate was the smallest when the fiber doping amount was 0.5%. (3) The quality loss rate of the 90d test pieces of different cement and basalt fibers is lower than the maintenance age of 28d under the same conditions, and with the increase of the number of freeze-thaws, the quality loss rate of all the test pieces
is increasing.

Based on basalt fiber and cement doping analysis of the freezing and thawing effect on cement curing wind accumulation sand test results loss of the machinery: (1) Basalt fiber cement cured wind-accumulated sand belongs to a multi-phase, non-uniform composite material system with structure. The surface and interior of the test piece without freezing and thawing cycle have micro-cracks or a small number of open pores due to temperature, humidity and other factors. After the freezing and thawing cycle, the water molecules enter the inside of the test piece through the pores, saturating the inner holes gradually. The resulting freezing bloating reaction causes the static water pressure and osmotic pressure of the holes inside the test piece to increase gradually, and the closed holes run through and increase in the direction of stress concentration. After melting, the wind sand particles that run through the hole inside the test piece are peeled out of the base body with the water release pressure, which freezes again and causes more serious secondary damage. (2) With the increase of cement doping, more cement slurry enters the inside of the test piece, filling the gap between the air-accumulated sand particles, forming more stable crystals to make it have a strong adhesion. Thus, the dry shrink cracks caused by premature evaporation of water are reduced, so that the flatness and smoothness of the test surface are improved, and the moisture entering the inside of the test piece is reduced. And with the increase of cement doping, the integrity and stability of the test piece itself are also improved, and the ability to resist the internal crystallization and freezing pressure of the test piece is also improved. (3) The bridging effect of basalt fiber increases the adhesion between the wind-accumulated sand particles inside the test piece, and the fiber has strong toughness, and the part of the test piece that is concentrated by stress due to the freezing and expansion is dissipated. However, too much basalt fiber doping, in the test piece molding caused the phenomenon of icing, destroy the wholeness of the test piece and aggravate its surface and internal cracks, holes phenomenon, and thus cause the quality loss rate rebound trend.

![Graph showing the change of mass loss rate when cement doping is 10%](image)

a. The change of mass loss rate when cement doping is 10%
b. The change of mass loss rate when cement doping is 15%

c. The change of mass loss rate when cement doping is 20%

Fig3 The law of change of mass loss rate

3.2 Side-limited pressure strength analysis

Figure 4 for the addition of basalt fibers and unmissed basalt fibers after freezing and melting after the non-side limit pressure test cracks produced conditions, not mixed with basalt fibers wind-accumulated sand curing parts after the non-side limit anti-pressure test, wide and dense cracks throughout the test piece itself and locally presented broken. When the fiber is mixed, the crack on the test piece decreases and the crack width decreases, which indicates that basalt fiber can resist the formation of cracks to a certain extent and reduce its extension on the test piece.

a: The condition of cracks in the test pieces without fiber  b: The condition of cracks in the test pieces mixed with fiber

Fig.4: Cracks in test specimens with different fiber content
Figure 5 shows the change law of the pressure-free strength of the wind-accumulated sand curing part under different conditions. Analysis figures a, b, c can be seen: (1) The pull resistance of basalt fibers can indirectly improve the side-limited pressure strength of cement cured wind-accumulated sand, and when the doping amount is 0.5%, the pressure resistance of wind-accumulated sand cement curing parts is the greatest. However, with the excessive increase of fibers, the fibers form a quidge between the test pieces when forming, so that their own bridging, toughness is not fully utilized, and destroyed the test piece substation on the fiber's grip force, so that the test piece inside the hole increased, penetration increased, thereby reducing the test piece resistance to external load capacity. (2) Cement hydration to form gel Ca (OH)$_2$, calcium silicate (C-S-H) gel, calcium aluminate (C-A1-H) gel can improve the mutual binding force between wind sand particles, thereby enhancing the pressure strength of wind sand curing. With the increase of cement doping, the gel inside the test piece gradually increases, and the cohesion between the molecules inside the structure is further improved, so the side-limited pressure strength of the test piece is the highest under the condition of 20% cement doping. (3) With the increase of the number of frozen melt cycles, basalt fiber cement solidified wind-accumulated sand test pieces due to frozen expansion force generated by the penetration pores gradually increased. The external shaft pressure at the test piece hole is prone to stress concentration phenomenon, which aggravates the damage of the test piece. Therefore, the higher the number of freezing and thawing cycles, the test piece without side limit pressure strength is also reduced. (4) 90d maintenance age test pieces, in the same number of freezing and thawing, cement doping, fiber doping under the non-side limit pressure strength is higher than 28d, and the maximum value is 12.4MPa. This is due to the longer the maintenance period, cement in the hydration of hydration heat caused by dry shrink stress, surface tension becomes smaller, test parts produced by micro-cracks reduced.

![Graph showing change in pressure strength](image)

a. The law of change of pressure strength when cement doping is 10%
The amount of basalt fiber doping/

b. The law of change of pressure strength when cement doping is 15%

c. The law of change of pressure strength when cement doping is 20%

Fig 5. Change rule of unconfined compressive strength

In order to further analyze the law that the number of freeze thaws has no side limit pressure strength change on different basalt fiber doping test pieces, Defining the loss rate of non-side limit pressure strength of basalt fiber cement cured wind-accumulated sand test pieces under different freezing and thawing cycles $V_t$, As shown in Formula (2): The smaller the value, the higher the side-limited pressure strength of the test piece under the freeze-thaw cycle. $R_{k,0}$ in the formula is the side-limited pressure strength of the test piece when the fiber doping amount is $k$; $R_{k,t}$ is the side-limited pressure strength of the test piece when the fiber doping amount is $k$ and the number of freeze thaws is $t$; $k$ is the amount of basalt fiber; $t$ is the number of freeze-thaw cycles.

$$V_t = \frac{R_{k,0} - R_{k,t}}{R_{k,0}} \quad (2)$$

As shown in Figure 6, the change trend of the loss rate and the number of freeze-thaws without side limit pressure strength of the test pieces is shown, As can be seen from the fitted damage model curve: The loss rate of non-side limit pressure strength gradually increased with the increase of the number of freeze-thaws, and the damage model curve obeyed the law of secondary multi-method change(e.g. Formula 3), And the fitting correlation coefficient is greater than 0.9. Different basalt fibers, cement doping, different maintenance age test pieces are in line with this trend, fitting results are found in Table 2, 3
The number of freeze-thaws corresponds to $V_t$ 

The function fits the curve

$$V_t = 0.0263t^2 - 0.0897t + 0.016842$$

$R^2 = 0.92453$

Fig 6. Trends of loss rate of unconfined compressive strength and number of freeze-thaw cycles 

$$V_t = at^2 + bt + c \quad (3)$$

$a$ and $b$ are the coefficients related to the number of freeze-thaw cycles, and $c$ is the intercept.

Tab 2 Fitting results of compressive strength loss rate and freezing and thawing cycles at 28d maintenance age

| Cement doping % | Fiber doping % | a       | b       | c       | R²       |
|-----------------|----------------|---------|---------|---------|----------|
| 10              | 0              | 0.02941 | -0.08824| 0.11765 | 0.99713  |
|                 | 0.1            | 0.02632 | -0.08947| 0.16842 | 0.92453  |
|                 | 0.3            | 0.01786 | -0.03214| 0.07    | 0.92774  |
|                 | 0.5            | 0.00257 | 0.05659 | 0.00769 | 0.9447   |
|                 | 0.7            | 3.8712×10⁻¹⁷ | 0.06667 | 0.05    | 0.96923  |
|                 | 1.0            | 9.4811×10⁻¹⁷ | 0.06957 | 0.05217 | 0.96923  |
|                 | 1.5            | 8.9247×10⁻¹⁷ | 0.07619 | 0.00952 | 0.96923  |

| Cement doping % | Fiber doping % | a       | b       | c       | R²       |
|-----------------|----------------|---------|---------|---------|----------|
| 20              | 0              | 0.01158 | -0.00463| 0.02703 | 0.97932  |
|                 | 0.1            | 0.00794 | 0.01238 | 0.02667 | 0.99694  |
|                 | 0.3            | 0.00456 | 0.02584 | 0.01277 | 0.99819  |
|                 | 0.5            | 0.00744 | 0.01577 | -0.00833| 0.97893  |
|                 | 0.7            | 0.00466 | 0.0264  | 0.01304 | 0.99819  |
|                 | 1.0            | 0.00997 | 6.6445×10⁻⁴ | 0.0186 | 0.97111  |
|                 | 1.5            | 0.00697 | 0.03136 | -0.02439| 0.93921  |

| Cement doping % | Fiber doping % | a       | b       | c       | R²       |
|-----------------|----------------|---------|---------|---------|----------|
| 30              | 0              | -1.671×10⁻¹⁷ | 0.04762 | 0.04762 | 0.99812  |

Tab 3 Fitting results of compressive strength loss rate and freezing and thawing cycles at 90d maintenance age

| Cement doping % | Fiber doping % | a       | b       | c       | R²       |
|-----------------|----------------|---------|---------|---------|----------|
| 10              | 0              | -1.671×10⁻¹⁷ | 0.04762 | 0.04762 | 0.99812  |
As can be seen from Tables 2 and 3: The correlation coefficient R² of the fitted results is greater than 0.9, indicating that under any conditions, the change law of the non-side pressure resistance loss rate and the number of freeze-thawing times of basalt fiber cement solidified wind solidified sand are highly consistent with the above-mentioned secondary polynomial change trend, indicating that the fitting injury model can better reflect the effect of the number of freeze-thawing times on the side-limiting strength of basalt fiber cement solidified wind sand.

4. Gray-associated entropy analysis.
In the sample of some random factors[11], the gray correlation entropy analysis method refines the correlation degree of the influence system index through data processing, and finds the main and secondary factors affecting the system and the difference of the influence on the system. In order to determine the degree of influence of cement doping, basalt fiber doping, freezing cycle number and maintenance age on the mass loss rate and non-side limit pressure strength respectively, the experimental data were analyzed for gray-associated entropy, the calculation steps are as follows, and the results are shown in Table 4.

Set up a reference column: \( x_0 = [x_0(1), x_0(2), \ldots, x_0(n)] \)

Compare columns: \( x_i = [x_i(1), x_i(2), \ldots, x_i(n)] \)

Initial value processing: \( x_i(k) = \frac{x_i'(k)}{x_i'(1)} \) \((k = 1, 2, \ldots, n; i = 1, 2, \ldots, m)\)

Get the no-measure outline reference column: \( x_0 = [x_0(1), x_0(2), \ldots, x_0(n)] \)

No outline comparison column: \( x_i = [x_i(1), x_i(2), \ldots, x_i(n)] \)

The correlation factor: \( r(x_0(k), x_i(k)) = \frac{\min_i \min_k [x_0(k) - x_i(k)] + \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \max_i \max_k |x_0(k) - x_i(k)|}\) Formula \( \xi \) is a resolution factor, usually taken 0.5

set \( R_i = \{r(x_0(k), x_i(k))|k = 1, 2, \ldots, r\} \) then the map, \( Map: R_i \rightarrow P_i \). The distribution density value
is: \[ p_h = \frac{r(x_0(h), x_i(h))}{\sum_{k=1}^{n} r(x_0(k), x_i(k))} \quad p_h \in P_i, \; h = 1, 2 \cdots n \]

Called a function. \[ H(R_i) = -\sum_{h=1}^{n} p_h \ln p_h \]

Is the entropy associated with gray. The gray entropy correlation is: \[ E(x_i) = \frac{H(R_i)}{\ln n} \]

| Gray entropy correlation | Number of freezes | Cement doping | Fiber doping | Number of freezes | Cement doping | Fiber doping |
|--------------------------|-------------------|--------------|-------------|-------------------|--------------|-------------|
| 28d                      | 0.73              | 0.6          | 0.92        | 0.7               | 0.52         | 0.51        |
| 90d                      | 0.7               | 0.57         | 0.54        | 0.7               | 0.54         | 0.54        |

The correlation degree of gray entropy of mass loss rate: a; No side limit pressure strength gray entropy correlation.

As can be seen from table 4, the correlation between the four parameters and the gray entropy of the mass loss rate is: Cement doping amount>number of freeze-thawing times>maintenance age>fiber doping; The correlation between the four parameters and the gray entropy with no side limit pressure strength is: Cement doping amount>maintenance age>number of freez-thaws>fiber doping. The correlation between two types of gray entropy can be seen: cement doping has the greatest effect on mass loss rate and sideless pressure resistance. This is because cement is the cement solidified wind sand gel material, the greater the amount of cement doping its glue wind sand effect is better, the more binding between the wind sand particles, the better the integrity of the wind sand curing parts, the higher the strength, so the higher the ability to resist external loading.

5. Conclusion

1. With the increase of basalt fiber doping, the quality loss rate of basalt fiber cement cured wind accumulation sand test pieces of different freezing and thawing cycles, cement doping, maintenance age, and the pressure-free strength showed the trend of decreasing first, increasing first and decreasing later. And in 0.5% basalt fiber doping, its mass loss rate is the smallest, no side limit pressure strength is the largest. Therefore, when the basalt fiber doping amount is 0.5%, the damage degree of the wind-accumulated sand curing part is minimal under the effect of freezing and thawing.

2. The test pieces of basalt fiber cement cured wind accumulation sand by freezing and thawing cycle were higher than those with 28 days of maintenance under different conservation age, and the test pieces with a conservation age of 90 days were higher than those with resistance to frost and thaw damage. Therefore, when using basalt fiber cement to cure wind-accumulated sand in the actual project, in order to improve its ability to resist frostbite damage, in accordance with the requirements of the specifications, should be as far as possible to increase its maintenance age.

3. By fitting the curve relationship between the loss rate of side-limited pressure resistance and the number of freeze-thaw cycles of cement cured wind solidified by basalt fiber cement, it is found that the development trend of the damage model is subject to the law of secondary polynomial change, and the correlation coefficient of fitting is greater than 0.9.

4. Through the analysis of the correlation degree of gray entropy, it is concluded that the effect of cement doping on the mass loss rate of wind-accumulated sand curing parts and the pressure strength without side limits are the greatest.

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