Effect of fiber reinforcement on mechanical properties of flow solidification of silt

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Abstract. In order to solve the brittle failure of cement flowing solidified sludge, basalt fiber and cement are mixed to prepare flowing solidified sludge. The fluidity and unconfined compressive strength tests of fluid solidified sludge with different cement and fiber content have been carried out. The results show that mixing basalt fiber into cement solidified fluid sludge will reduce its fluidity and increase its unconfined resistance Compressive strength; there is an optimal amount of basalt fiber, and its optimal amount is affected by the amount of cement; with the increase of curing age, the compressive strength of the sludge solidified with fiber cement increases gradually; the solidified sludge is unconfined for 14d and 28d The unconfined compressive strength has a linear relationship with the 7d unconfined compressive strength

Keywords: flow solidification, basalt fiber, unconfined compressive strength.

1. Introduction
Dredged silt generally has the characteristics of high water content, large compressibility, fine particle size, and high organic content. It not only takes up a lot of land resources, but also causes serious secondary pollution. The resource utilization of silt is the ultimate outlet for dredged silt treatment and disposal[1].

Ding Jianwen [2] proposed that the dredged sludge with high moisture content should be flowed and solidified, so that it can be constructed by pumping like concrete to achieve the purpose of efficient construction.

When the cement is mixed with fluid and solidified, the solidified body will appear brittle failure. Some scholars have analyzed the mechanical properties of fiber reinforced solidified silt soil. There is an optimal amount of fiber, and the improvement effect of fiber on solidified sludge depends on the amount of fiber, the bonding force and friction between the fiber and the sludge particles[3].

Namdar et al. [4] found that the polymer fiber not only improves the strength of the soil, but also converts its brittle failure mode into a ductile failure mode, and also increases the water stability of the solidified soil.Khattak et al.[5]showed that the incorporation of fibers can improve the tensile strength of silt-solidified soil.Carruth et al.[6]analyzed the mechanical properties of fiber-reinforced solidified silt soil, and the results showed that the incorporation of fibers not only increased the elastic modulus of silt-solidified soil, but also benefited the development of soil ductility.Ye timoglu T[7],Tang Chaosheng[8]and others have shown that with the addition of fibers, the strength of the sample can be
effectively increased, the strain of the sample during failure, and the ductility of the sample can be increased. The incorporation of basalt fiber can enhance the plastic properties of cement-solified aeolian sand, so that the cement-solified aeolian sand specimen can still withstand a certain load after failure, and there is residual stress, which is conducive to improving the safety and stability of the project [9].

The silt soil treated with traditional solidified materials may have defects such as brittle cracking damage, softening and disintegration by soaking in water, and it is necessary to use fiber materials to reinforce it to avoid brittle damage. This experiment takes the sludge from Wenzhou Economic and Technological Development Zone as the research object, and carries out unconfined compressive strength test and fluidity test on fluid solidified sludge with different ages, different cement content, and different fiber content.

2. Experimental Program

Materials. The sludge used in the test was taken from the Wenzhou Economic and Technological Development Zone, and a series of tests were carried out on the water content, density, and liquid-plastic limit. The basic indicators are shown in Table 1. The cement used in the test is ordinary Portland cement P.O42.5.

The moisture content of the undisturbed soil is 55.2%, the plastic limit is 20.0%, the liquid limit is 52.1%, the plasticity index is 32.1, the liquidity index is 1.10, the void ratio is 1.55, and the natural density is 1.65g/cm³.

The particle gradation of the undisturbed soil is shown in Figure 1. The content of fine particles is relatively high, with 28.7% smaller than 5μm and 3.6% larger than 75μm.

![Figure 1. Particle size distribution curve.](image)

Basalt fiber is 12mm in length, 16~22μm in diameter, 2.62~2.65 g/cm³ in density, tensile strength ≥3200MPa, elastic modulus 90~105GPa, and elongation at break 2.7~3.6%.

Method. To explore the effect of fiber reinforcement on the characteristics of cement flowing and solidified silt, this paper configures 5 kinds of solidified silt soil samples with different reinforcement ratios and 3 different cement content, and the curing period is 7d, 14d, 28d. The water-solid ratio of the sample is 1.2, the fiber content is 0, 0.2%, 0.4%, 0.6%, and 0.8%, and the cement content is 8%, 11%, and 14%.

Define the fiber and cement content as:

\[ p_f = \frac{m_f}{m} \quad p_c = \frac{m_c}{m} \]

In the formula, \( m_s \) is the dry weight of soil, \( m_f \) is the quality of the fiber, \( m_c \) is the quality of the cement, and \( m \) is Total mass of solidified sludge.
According to the test mix ratio, mix and stir an appropriate amount of water, fiber, cement and undisturbed sludge into three layers into a customized mold, vibrate in layers, and discharge air bubbles. The size of the produced sample is $\Phi 3.91 \text{cm} \times 8 \text{ cm}$ (diameter $\times$ height).

After the sample is sealed, put it into a curing box with a temperature of $20 \pm 2^\circ\text{C}$ and a humidity of 95% or more for curing, and demoulding after 24h. The demolded samples were cured to 7d, 14d and 28d, and the unconfined compressive strength test was carried out. The unconfined compressive strength experiment uses the YYW-2 unconfined pressure gauge, and the strain rate is controlled to 1mm/min during the test.

Flow solidification requires that the fluidity of the mixture meets the requirements of construction methods such as pumping, so the fluidity test of the mixture is required. In this test, the fluidity test is carried out according to the relevant Japanese regulations.

The customized fluidity test cylinder has a diameter and height of 8cm. During the test, place it on the plexiglass, put the mixture into the cylinder three times, and shake after each filling to make it compact. Scrape the surface of the cylinder, wipe off the side of the cylinder and the residual mixture on the plexiglass, quickly lift the cylinder, and after the mixture is spread, the average value of the maximum diameter and the minimum diameter is the fluidity. The group carried out three parallel tests, and the average value was taken.

3. Results And Analysis

Liquidity Analysis. Explore the influence of fiber content on flow value under different cement content conditions. As shown in Figure 2, when the water-to-solid ratio is 1.2, as the fiber content increases, the fluidity decreases, and the magnitude of the decrease is first large and then small, the trend is curved, and the fluidity decreases The faster fiber content is 0%~0.4%. When the fiber content is between 0.4%~0.8%, the fluidity change is small.

Unconfined Compressive Strength Analysis. As shown in Figure 3, when the water-solid ratio is 1.2 and the curing age is 7 days, the unconfined compressive strength first increases and then decreases. In the case of different cement content, the fiber content corresponding to its peak strength is different.
Figure 3. Unconfined compressive strength–cement content and curing age relationship.

When the curing age is 7 days, when the cement content is 8%, its peak strength is 101kPa, which appears at the fiber content of 0.6%, which is an increase of 84.6% compared to the strength without fiber. When the cement content is 11%, its peak strength is 195kPa, which appears at 0.4% fiber content, which is 71.7% higher than the strength without fiber content. When the cement content is 14%, its peak strength is 250.4kPa, which appears at the fiber content of 0.2%, which is 23.7% higher than when the fiber is not blended.

Effect Of Curing Time. When the water-solid ratio is 1.2, as shown in the figure, the longer the age, the greater the unconfined compressive strength. With the increase of age, the higher the fiber content, the greater the increase in unconfined compressive strength. When the curing age is relatively short, the degree of cement hydration is insufficient. As the degree of cement hydration increases, the friction strength between the basalt fiber and the soil particles increases, which increases the unconfined compressive strength.

When the cement content is 8%, the peak strength appears at the fiber content of 0.6%. When the curing age is 7d, 14d, and 28d, the unconfined compressive strength is 101kPa, 136.2kPa, and 173.1kPa, respectively. The intensity of 14d and 28d were 1.35 and 1.71 times that of 7d, respectively.

As shown in Figure 4, the fitting results of the relationship between unconfined compressive strength $q_{u28d}(q_{u14d})$ and $q_{u7d}$ are linear. R-squares are 0.96712 and 0.99555, respectively. The fitting results are as follows:

\[
q_{u14d} = 23.011911 + 1.14797q_{u7d}
\]
\[
q_{u28d} = -3.47871 + 1.6617q_{u7d}
\]
Stress-Strain Curve. When the water-solid ratio is 1.2, under different fiber content, the stress-strain relationship is shown in the figure. As the fiber content increases, the strain corresponding to the peak stress intensity increases. The higher the cement content, the greater the fiber content, and the more gentle the corresponding stress-strain curve.

![Stress-Strain Curves](image)

Figure 5. Stress-strain curves.

Destruction Form. As shown in Figure 6, when the water-solid ratio is 1.2, the cement content is 11%, and the curing age is 14 days, the failure of the solidified sludge without fiber is brittle, and the crack width is large. When it is completely destroyed, the sample part Separated and dropped. With the increase of fiber content, the width of the crack gradually decreases, and there is no more separation, falling and collapse of the sample. The development of cracks no longer penetrates, avoiding brittle failure.

![Destruction Form](image)

Figure 6. Destruction form.
4. Conclusions
(1) When the curing age is 28 days, the cement content is 8%, the corresponding peak strength appears at the fiber content of 0.6%, and its value is 173.1kPa, the cement content is 11%, and the corresponding peak strength appears when the fiber content is 0.4%, the value is 300kPa, and the corresponding peak strength appears at the fiber content of 0.2%, and its value is 417.4kPa.

(2) As the curing age increases, the unconfined compressive strength of the sample increases. The fitting result of the $q_{u28d}(q_{u14d}) \sim q_{u7d}$ relationship is a straight line, R-squares are 0.96712 and 0.99555.

(3) With the increase of fiber content, the width and number of cracks when the sample is destroyed will decrease, and the sample will no longer be separated, dropped and collapsed, and the cracks will no longer develop through, avoiding brittle failure.

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