Strength analysis of the cast-in-situ foamed lightweight soil materials

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Abstract: In order to better use the cast-in-situ foamed lightweight soil for soft soil roadbed filling project, based on mechanical properties test under different working conditions study unconfined compressive strength variation characteristics of cast-in-place foamed lightweight soil. Analysis of tension and bending strength and fatigue life of the cast-in-situ foamed lightweight soil by fatigue resistance test. The corrosion resistance test was used to further analyze the unconfined compressive strength loss and mass loss of the cast-in-situ foamed lightweight soil under different corrosion conditions. The results show that as soft foundation backfill material its mechanical properties are excellent, however, the fatigue life is greatly affected by the stress ratio, and the cast-in-situ foamed lightweight soil is poor in acid corrosion resistance, diesel corrosion resistance and salt-spray corrosion resistance.

1. Introduction

The cast-in-situ foamed lightweight soil is fully foamed by mechanical means, and evenly mixes the foam with the cement slurry for cast-in-situ construction or mold forming. The material has the characteristics of light weight, good fluidity and excellent mechanical properties after hardening. It can be used to reduce road settlement when replacing soft soil backfill, and has become a new technical means for highway soft soil roadbed treatment[1-9]. The foamy lightweight soil was first prepared by Japanese scholars in the 1990s using foam concrete technology[6]. Some scholars in China have studied the preparation and engineering properties of foamed lightweight soil. Liu Han-long et al[7] analyzed the characteristics, construction technology and application range of foam lightweight soil. Gu Da-huan et al[8] studied the effect of water-cement ratio and bubble incorporation on the fluidity and separation rate of the cast-in-situ foamed lightweight soil. Zhu Hong-ying et al[9] explored the influence of various base materials of the cast-in-situ foamed lightweight soil on dry density, compressive strength and water absorption of materials. At present, the research on the cast-in-situ foamed lightweight soil mostly focuses on the mix proportion and physical and mechanical properties. However, the strength, fatigue resistance and corrosion resistance of the cast-in-situ foamed lightweight soil under different working conditions are rarely studied. It restricts the popularization and application of the cast-in-situ foamed lightweight soil in soft foundation treatment engineering.

Therefore, this article based on mechanical properties test under different working conditions study unconfined compressive strength variation characteristics of the cast-in-place foamed lightweight soil. Analysis of tensile strength and fatigue life of the cast-in-place foam lightweight soil by fatigue resistance test. The corrosion resistance test was used to further analyze the unconfined compressive
strength loss and mass loss of the cast-in-situ foamed lightweight soil under different corrosion conditions. It provides a useful reference for the engineering application of cast-in-place foamed lightweight soil.

2. Test raw materials
The raw materials for the preparation of the cast-in-situ foamed lightweight soil mainly include foaming agent, cementing material (cement), water and fine aggregate sand. The composition ratio of the cast-in-situ foamed lightweight soil used in the test was shown in Table 1. The test sand was made of aeolian sand and the cement was made of 32.5 R type Portland cement. During the test, the foaming agent was diluted with water at a dilution rate of 40 times, and the diluted foaming liquid was added to the foaming machine for full foaming until a large amount of stable foam was produced. Then, the cement and sand and remaining water were added to the mixer and stirred into a cement slurry (mixing time is not less than 2 minutes). Finally, the foam and the cement slurry were mixed and stirred (mixing time is not less than 2 minutes). Thereby, preparing the cast-in-situ foamed lightweight soil. Two standard specimens of 100 mm × 100 mm × 100 mm and 100 mm × 100 mm × 400 mm were made from the cast-in-place foamed lightweight soil, and removed the mold after 24 hours, packed the specimens with a plastic film, and then maintained indoor for 28 days, in order to be used in the follow-up test.

| serial number | Composition of the mix proportion | Cement (kg/m³) | Sand (kg/m³) | Water (kg/m³) | foaming agent (L/m³) | bulk density (kN/m³) |
|---------------|----------------------------------|----------------|--------------|---------------|----------------------|--------------------|
| A             |                                  | 300            | 300          | 205           | 1.16                 | 8.30               |
| B             |                                  | 275            | 550          | 241           | 0.88                 | 10.9               |
| C             |                                  | 400            | 300          | 255           | 1.00                 | 9.8                |
| D             |                                  | 350            | 0            | 220           | 1.20                 | 6.00               |

3. Mechanical properties under different working conditions
Considered the cast-in-situ foamed lightweight soil used for soft foundation treatment will be affected by groundwater and pavement water seepage and seasonal temperature changes for a long time. Therefore, the mechanical properties of the cast-in-situ foamed lightweight soil materials were mainly studied under dry-wet cycle and freeze-thaw cycle conditions.

3.1. Dry-wet cycle conditions
The 100 mm × 100 mm × 100 mm specimens made with four mix proportion A, B, C and D. The test procedure was referred to the “Test Method for Performance of Autoclaved Aerated Concrete” (GB/T 11969-2008), China. The specimens was placed in a thermostat at 50 ℃ for 2 days, Then place it in water for 1 day (completely immersed) as a single cycle of dry-wet cycle. The unconfined compressive strength of the specimens after 0, 1, 5 and 10 dry-wet cycles was measured. At the same time, in order to evaluate the durability of the cast-in-situ foamed lightweight soil under the dry-wet cycle conditions, the durability coefficient can be introduced, as shown in formula:

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\text{Durability coefficient} = \frac{\text{Unconfined compressive strength after external factors}}{\text{Unconfined compressive strength of original specimens}} \quad (1)
\]

The test results are shown in figures 1 and 2 below.
Analysis of figures 1 and 2 shows that under the initial condition, the unconfined compressive strength of the cast-in-situ foamed lightweight soil specimens with four mix proportion of A, B, C and D were 0.64 MPa, 1.36 MPa, 1.56 MPa and 2.19 MPa. After 10 dry-wet cycles, the unconfined strength decreases were 0.02 MPa, 0.1 MPa, 0.01 MPa and 0.29 MPa. “Technical specification for design and construction of cast-in-situ foamed lightweight soil subgrade” (TJG F1001-2011), China stipulates that the 28-day unconfined compressive strength should be not less than 0.6 MPa. During the test, the unconfined compressive strength of the cast-in-situ foamed lightweight soil was always higher than 0.6 MPa. The durability coefficient of the cast-in-place foamed lightweight soil with A, C, B and D gradation decreased by 0.03, 0.07, 0.01 and 0.13. After dry-wet cycle test, the decrease range was small, indicating that the strength characteristics of the cast-in-situ foamed lightweight soil under dry-wet cycle conditions were good.

3.2. Freeze-thaw cycle conditions

The mechanical properties of 100 mm × 100 mm × 100 mm specimens made of four mix proportion of A, B, C and D were tested under dry-wet cycling conditions. The test procedure was referred to the “Test Method for Performance of Autoclaved Aerated Concrete” (GB/T 11969-2008), China. The specimens were frozen for 24 hours at -24 °C, and then melt in a constant temperature and constant humidity box at 21 °C for 24 h as a cycle. The unconfined compressive strength of specimens in the initial state and the unconfined compressive strength of specimens after 1, 5 and 10 freeze-thaw cycles were measured, and the durability coefficient of the specimens was calculated according to formula 1, as shown in figures 3 and 4.
Analysis of figures 3 and 4 shows that the initial unconfined compressive strengths of the cast-in-situ foamed lightweight soil of mix proportion A, B, C and D were 0.7 MPa, 1.4 MPa, 1.63 MPa and 2.1 MPa, after 10 freeze-thaw cycles, the unconfined strength decreases were 0.07 MPa, 0.19 MPa, 0.08 MPa and 0.24 MPa, and during the test, the unconfined compressive strength of the cast-in-situ foamed lightweight soil was always higher than 0.6 MPa. After 10 freeze-thaw cycles, the durability coefficient of mix proportion B decreased the most (0.14), while that of mix proportion C decreased the least (0.05). The mechanical properties of cast-in-situ foamed lightweight soil were better under freeze-thaw cycles.

4. Fatigue resistance
The determination of tension and bending strength of the cast-in-situ foamed lightweight soil is the basis for evaluating its fatigue resistance. Referred to "Test Methods of soils for Highway Engineering" (JTG E40-2007), China. The test used a bending test based on the three-point loading method, the mix proportion of specimens was a basic mix proportion A, the trabecular specimen size was 100 mm × 100 mm × 400 mm. The test results are shown in figure 5.

Analysis of figure 5 shows that minimum and maximum values of the failure loads were 3114.24 N, 3484.52 N, and the coefficient of variation was 4.83 %. The maximum and minimum values of tension and bending strength were 0.99 MPa and 0.88 MPa, and the coefficient of variation was 5.02 %.

The fatigue life of the cast-in-situ foamed lightweight soil was determined by fatigue test. Referred to the "Test Methods of Cement and Concrete for Highway Engineering" (JTG E30-2005), China. The load controlling mode adopts stress control, loading process selects the loading frequency as continuous 10 Hz, and the load waveform adopts sine wave. According to the ratio of the ultimate stress obtained by one loading and the repeated stress, five stress ratios of 0.92, 0.83, 0.73, 0.64, and 0.55 were selected. In the test process, the fracture of the specimen was taken as the criterion of fatigue failure. The single logarithmic fitting curve was used to establish the functional relationship between the stress ratios of the cast-in-situ foamed lightweight soil and the fatigue life. The test results are shown in figure 6.
Analysis of figure 6 shows that the correlation coefficient of the fitting curve equation was 0.962, it shows that the linear relationship between fatigue life $Y$ and $10^{(-11.292x+12.167)}$ was significant. The number of load cycles measured by the 0.55 and 0.92 stress ratios was 238023 and 30. The fatigue life of the specimen was greatly affected by the stress ratio, the fatigue life of the same specimen will gradually decrease due to the increase of the stress ratio, and the discreteness of fatigue life was large.

5. Corrosion resistance

The corrosion resistance test of the cast-in-situ foamed lightweight soil adopts the basic mix proportion A, and the specimens size was 100 mm $\times$ 100 mm $\times$ 100 mm. Take one of the specimens into the salt spray test box (5 weeks), and the other three specimens were immersed in 0.4 mol/L sulfuric acid solution, saturated sodium hydroxide solution and diesel for 24 h. The test results are shown in table 2.

| serial number | etching condition | Appearance after test | mass loss (%) | Unconfined compressive strength loss (%) |
|---------------|-------------------|-----------------------|---------------|----------------------------------------|
| 1             | Acid corrosion    | Surface looseness     | 12.1          | 21.1                                   |
| 2             | Alkali corrosion  | Normal                | 2.3           | 7.3                                    |
| 3             | Diesel corrosion  | Normal                | 1.1           | 17.7                                   |
| 4             | Salt-spray        | Normal                | 3.2           | 19.3                                   |

According to table 2, compared with other test items, the surface appearance of the acid corrosion test was loose, and the loss rate of quality and unconfined compressive strength was large, which indicates that the acid corrosion resistance of the cast-in-situ foamed lightweight soil materials was poor. The diesel corrosion resistance and salt-spray corrosion resistance of cast-in-situ foamed lightweight soil were comparable, and the alkali corrosion resistance of the cast-in-situ foamed lightweight soil was better.

6. Conclusion

(1) After 5 cycles of dry wet cycling test, the unconfined compressive strength of the cast-in-situ foamed lightweight soil decreased by 10%~20%, then tended to be stable. It had good mechanical properties under dry-wet cycle conditions.

(2) Under freeze-thaw cycles, the unconfined compressive strength of the specimens in first cycle decreased obviously, then tended to be stable. During the test, no damage was found on the surface of the cast-in-situ foamed lightweight soil specimens, and its mechanical properties were excellent under freeze-thaw cycles.

(3) The fatigue life of the specimen is greatly affected by the stress ratio, the fatigue life of the same specimen will gradually decrease due to the increase of the stress ratio, and the discreteness of fatigue life is large.

(4) The cast-in-situ foamed lightweight soil has good alkali corrosion resistance, but its mechanical properties are poor under the condition of diesel oil, salt spray and acid corrosion.

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