Experimental study on microstructure characters of foamed lightweight soil

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Abstract. In order to verify the microstructure of foamed lightweight soil and its characters of compressive strength, four foamed lightweight soil samples with different water-solid ratio were selected and the microstructure characters of these samples were scanned by electron microscope. At the same time, the characters of compressive strength of foamed lightweight soil were analyzed from the microstructure. The study results show that the water-solid ratio has a prominent effect on the microstructure and compressive strength of foamed lightweight soil, with the decrease of water-solid ratio, the amount and the perforation of pores would be reduced significantly, thus eventually forming a denser and fuller interior structure. Besides, the denser microstructure and solider pore-pore wall is benefit to greatly increase mechanical intensity of foamed lightweight soil. In addition, there are very few acicular ettringite crystals in the interior of foamed lightweight soil, its number is also reduced with the decrease in water-solid ratio.

1. Introduction

According to the related study [1], the microstructure characters of materials mainly reflect two problems. On the one hand, the microstructure feature is a reflection of size, amount, shape, connection mode and arrangement of solid, liquid, gas-phase materials. On the other hand, engineering properties in macro performance of materials are also greatly determined by its microstructure, that is to say, the material performance is particularly illustrated in its microstructure features.

Foamed lightweight soil is a new lightweight materials, which produced by cement, fly ash, foam and water in appropriate proportions [2]. As a new kind of artificial materials, in the whole solid-liquid-gas phase system of foamed lightweight soil, the size and shape of gas pore which are the most important parameters determine the distributing characteristic of other two phases and the microstructure characteristics such as the connection mode and arrangement. Besides, the special physical and mechanical properties and durability of foamed lightweight soil are also by its microstructure features [3].

In fact, so many engineering properties in nature could be discovered by studying foamed lightweight soil on microstructure characters. Furthermore, there is a more scientific explanation for
its behaviors of mechanics and compressive strength. Therefore, four foamed lightweight soil samples with different water-solid ratio were selected in this paper and the microstructure of these samples was scanned by electron microscope. The changing rule of unconfined compressive strength was also analyzed from its microstructure features.

2. Protocol

2.1. Determination of the Mixture Ratio
In order to comparatively analyze the influences on the microstructure characters by different mixture ratio, four foamed lightweight soil samples with different water-solid ratio in Table 1 were selected to be scanned by electron microstructure based on some relevant experimental researches [4,5], and theirs physical and mechanical performance indicators also as shown in the Table 1.

| Test number | Water-solid ratio | Each component | Flow value (mm) | Moist unit weight (kN/m³) | 28d Unconfined compressive strength (MPa) |
|-------------|-------------------|----------------|-----------------|--------------------------|------------------------------------------|
| A1          | 1:1.70            | 253            | 108             | 212                      | 26                                      | 209                                      | 5.29                                    | 0.512                                  |
| A2          | 1:1.80            | 258            | 111             | 205                      | 27                                      | 189                                      | 5.56                                    | 0.621                                  |
| A3          | 1:1.90            | 263            | 113             | 198                      | 27                                      | 172                                      | 6.11                                    | 0.874                                  |
| A4          | 1:2.00            | 267            | 115             | 191                      | 27                                      | 158                                      | 6.31                                    | 0.956                                  |

2.2. Test Samples Preparation
Test samples were formed for the cube sample with the mixture ratio in Table 1, and had a standard curing for 28d. 28 days later, the length of sample should be captured for no more than 1cm, and its height should be no more than 6mm, as the actual sample for microstructure scanning.

As to acquire microstructure images of high quality for observing, the bottom of sample should be cut flat as far as possible, and lightly remove the suspended particles on the sample surface by using the rubber suction bulb. Besides, samples should be ready for vacuum suction and gilding treatment in the carbon coater for about 40min, as shown in Figure 1. And test samples after gilding treatment can be seen in Figure 2.

2.3. The Testing Instrument and Method
The SEM refers to the system that using some very fine electron beams to scan the specimen surface, and collecting bunches of electrons that is re-emitted to form signals, and then feeding them back into
the picture tube. In the end, we can see some clear images by adjusting the magnification, contrast ratio and focusing.

In this paper, the electron microscope was the HITACHI S-570, as shown in Figure 3. Observations multiple, 70 times, 140 times, and 600 times magnification were selected.

![Figure 3. SEM](image)

3. The Microstructure Analysis

3.1. Overall Microstructure Analysis

The overall microstructure profile would be scanned at 70 times SEM, the microstructures of foamed lightweight soil at the water-solid ratio of 1:1.70, 1:1.80, 1:1.90 and 1:2.00, as shown in Figure 4.

It can be clearly seen from Figure 4, there are a great mass of independent and closed pores in the inside soil of foamed lightweight soil, and the main shape of pores are round, small parts are irregular. Thus, the subject structure of foamed lightweight soil consists of these different size pores.

With comparative analysis of SEM micrograms, it is obvious that different water-solid ratio has strong influence on pores include size, amount and shape. With the decrease of water-solid ratio, both the amount of pores and aperture could be significantly reduced, the perforation of the pore also would be shallower. Therefore, a more compacted and fuller structure would gradually form. In other words, when the water-solid ratio is 1:1.70, the interior structure of foamed lightweight soil has the largest amount and the highest concentration of pores, but the minimum content of solid particles, so this overall structure of foamed lightweight soil is relatively porous. However, when the water-solid ratio is 1:2.00, the amount and concentration of pores is the least and the most discrete, but the maximum content of solid particles, so this overall structure of foamed lightweight soil is denser.

The Table 1 shows that unconfined compressive strength of foamed lightweight soil would increase gradually with the decrease of water-solid ratio. So far as the microcosmic aspect concerned, the interior structure of foamed lightweight soil about pore and pore wall is the key to determine its unconfined compressive strength. In fact, the pore wall surrounds the pore is the essential provider of unconfined compressive strength of foamed lightweight soil. The pore wall is more complete and denser with the decrease of water-solid ratio, it would also significantly reduce the void content of foamed lightweight soil. Therefore, unconfined compressive strength of foamed lightweight soil would gradually improve.
3.2. Locality Microstructure Analysis

The locality microstructure profile would be scanned at 140 times SEM, microstructures of foamed lightweight soil at the water-solid ratio of 1:1.70, 1:1.80, 1:1.90 and 1:2.00, as shown in Figure 5.

It is more clearly observed in Figure 5, when the water-solid ratio is large, there are relatively more broken and overhead gas pores in the interior structure, the pore wall structure is incomplete and the percentage of solid matters is very little. There is no doubt that unconfined compressive strength of foamed lightweight soil is lower from macroscopic point of view. On the contrary, when the water-solid ratio is small, the microstructure is becoming denser. There are almost no pores among particles, and content of solid particles is relatively large. Therefore, from macroscopic point of view, it is beneficial to develop the unconfined compressive strength of foamed lightweight soil.

3.3. Representative Microstructure Analysis

The representative microstructure profile would be scanned at 600 times SEM, microstructures of foamed lightweight soil at the water-solid ratio of 1:1.70, 1:1.80, 1:1.90 and 1:2.00, as shown in Figure 6.

It is obvious observed in Figure 6, there are very few acicular ettringite crystals existing in the interior of foamed lightweight soil, which is the hydrate product of cement. By comparison of microstructure pictures with different water-solid ratio, when the water-solid ratio becomes larger, the structure of cement materials would become more porous, so there has greater space to produce more
ettringite crystals. On the other hand, the smaller the water-solid ratio, the denser the structure of cement materials is, the less the gas pore is, so the less amount of ettringite crystals produced in the interior structure.

![Microstructure Images](image_url)

**Figure 6.** Microstructure of 600 times magnification

4. Conclusion

This paper presents the microstructure characters of foamed lightweight soil and its compressive strength by electron microscope. Bases on the above results, the following conclusions can be drawn.

1. Difference of water-solid ratio causes great changes in the overall organizational structure of foamed lightweight soil. With the decrease of water-solid ratio, the amount and the perforation of pores would be reduced significantly, the denser framework structure and fuller interior structure are gradually formed.

2. Difference of water-solid ratio also imposes an effect on its structural form about pore and pore wall. The larger water-solid ratio can result in the broken and porous pore-pore wall structure, but the smaller water-solid ratio would result in the dense and integrated pore-pore wall structure.

3. According to the SEM images, there are very few acicular ettringite crystals in the interior of foamed lightweight soil, its number is also reduced with the decrease in water-solid ratio.

4. From the microstructure point of view, the pore wall surrounds the pore is the essential provider of unconfined compressive strength of foamed lightweight. With the decrease of water-solid ratio, the pore wall is more complete and denser, cement materials gradually replace pores and the cement materials is the significant factor which affects foamed lightweight soil compressive strength characteristics Therefore, unconfined compressive strength of foamed lightweight soil would gradually improve.

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