ASSESSMENT OF STRENGTH DEVELOPMENT OF PS ASH-TREATED CLAY BASED ON THE WATER ABSORPTION PERFORMANCE OF PS ASH

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1. INTRODUCTION

Owning ability to absorbing water, paper sludge ash (PS ash), a sustainable material, PS ash can successfully stabilize soft clay in a short time. By considering the water absorption performance of PS ash, strength characteristics of the clay treated with PS ash can be assessed through the modified water content instead of the measured water content.

2. INVESTIGATION METHOD

The Ao clay slurry was stabilized by PS ash at different addition ratios, A_{PS}, identified as the ratio by weight of the PS ash to dry Ao clay. The treated clays then were cured in sealed condition with different curing periods at a room temperature of 20 °C and for different curing periods. The consistency and strength characteristics of the treated clay then were investigated by a series of tests for the liquid limit, plastic limit, water content and cone index according to the JGS 0122, 0141, 0711 and 0716. Details of mixing ratios and curing conditions of treated clays for tests are shown in Table 1 and 2. In addition, using the method proposed by Phan et al., (2021), the water absorption performance of PS ash, W_{ab}, was determined as shown in Table 3.

3. EFFECTS OF PS ASH ON CONSISTENCY PROPERTIES

As shown in Fig. 1, the liquidity index, I_L, of PS ash-treated clay decreased as the A_{PS} increased, indicating that the fluidity of the treated clays disappeared gradually with the increase in A_{PS}. Furthermore, Fig. 1 shows that I_L decreased as t increased. The fact reveals that the change in W_{ab} causes the treatment performance of PS ash change with the increase in the curing period even under the sealed curing condition.

4. EFFECTS OF PS ASH ON STRENGTH PROPERTIES

Fig. 2 shows the correlation between the cone index, q_c, and liquidity index, I_L, of the treated clay, in which I_L was obtained from A_{PS} = 5%, 10%, 20% cases for the PS ash-treated clay with $w_0 = w_L$. The q_c–I_L relation of Ao clay with various water contents was investigated to perform a comparison. It was discovered that the q_c–I_L correlation of the PS ash -treated clay was similar to that of Ao clay, in which q_c increased significantly with the decrease in I_L, particularly when I_L became less than 0.12. As shown in Fig.1, I_L depended on not only the addition ratio, A_{ps}, but also the sealed curing period, t. Therefore, it suggests that the q_c may be influenced by the W_{ab}.

When a PS ash is added to soil, part of the free clay-water is absorbed by the PS ash and behaves as restrained water and therefore cannot interact with clay particles, as shown in Fig. 3. However, for the water content measurement based on JGS 0122, the water content was measured by adjusting the temperature to 110±5 °C in the drying oven such that the restrained water evaporated (disappeared) together with the free clay water. In this

Table 1. Conditions of treated clays for test of consistency characteristics

Initial water content of Ao clay, w_0 (%)	Addition ratio, A_{PS} (%)	Curing period, t
40.7 ($w_0 = w_L$)	5, 10, 15, 20	3 h, 3 d, 7 d, 28 d
	25	3 h, 3 d, 7 d

Table 2. Conditions of treated clays for cone index tests

Initial water content of Ao clay, w_0 (%)	Addition ratio, A_{PS} (%)	Curing period, t
40.7 ($w_0 = w_L$)	5, 10, 20	3 h, 3 d, 7 d, 28 d
61.05 ($w_0 = 1.5w_L$)	25, 50	3 h, 3 d, 7 d
81.4 ($w_0 = 2w_L$)	40, 50, 60	3 h, 3 d, 7 d, 28 d

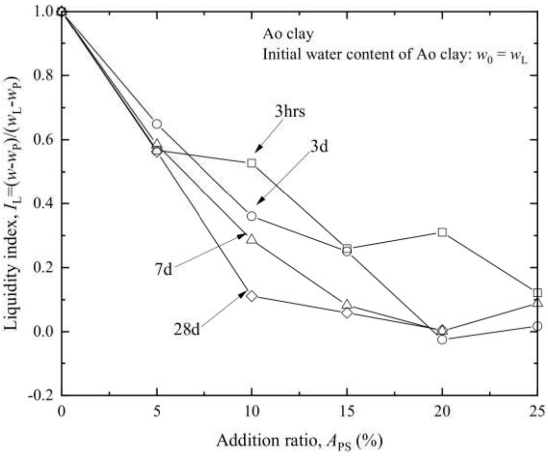

Figure 1. I_L - A_{PS} relation of PS ash-treated clay

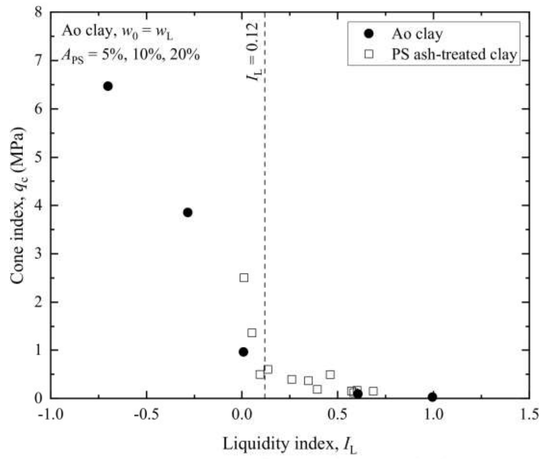

Figure 2. q_c - I_L of PS ash-treated clay

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case, the measured water content, w, and soil behavior did not match. Therefore, w was modified by considering the restrained water as a solid rather than water. The modified water content is denoted as w^* herein. The measured water content, w, and modified water content, w^*, can be expressed as Eq. 1 and 2, respectively.

$$w = \frac{m_w}{m_s + m_{ab}} \times 100 \qquad (1)$$

$$w^* = \frac{m_w - m_{abw}}{m_s + m_{ab} + m_{abw}} \times 100 \qquad (2)$$

In addition, the A_{PS} and the W_{ab}, of the PSAS can be expressed respectively by the Eq. 3 and 4, respectively.

$$A_{PS} = \frac{m_{ab}}{m_s} \times 100 \qquad (3) \qquad\qquad W_{ab} = \frac{m_{abw}}{m_{ab}} \times 100 \qquad (4)$$

Combining equations (1) to (4), the w^* (in %) can be calculated by the following equation:

$$w^* = \frac{\frac{w}{100}\left(1 + \frac{A_{PS}}{100}\right) - \frac{A_{PS}}{100} \times \frac{W_{ab}}{100}}{1 + \frac{A_{PS}}{100}\left(1 + \frac{W_{ab}}{100}\right)} \times 100 \qquad (5)$$

The correlations between the q_c and the the simplified liquidity index, I'_L, and between the q_c and the modified liquidity index, I^*_L, are shown in Fig. 4 and 5, respectively. The I^*_L of the treated clay is calculated by the Eq. 6 using modified water content, w^*, of the treated clay together with the liquid and plastic limits of Ao clay instead of those of treated clays. The I'_L of the treated clay is calculated by the Eq. 7 with using measured water content, w, of the treated clay together with the liquid and plastic limits of Ao clay:

$$I^*_L = \frac{w^* - w_P}{w_L - w_P} \qquad (6) \qquad\qquad I'_L = \frac{w - w_P}{w_L - w_P} \qquad (7)$$

It is obtained that the q_c–I^*_L relations (Fig.5) is better and more reasonable than the q_c–I'_L relations (Fig. 4). The scattering in q_c–I^*_L relations is also smaller than that in q_c–I'_L relations. The I^*_L at which q_c began to significantly increase depended on w_0. The lower the w_0, the higher was the value. In particular, in the case of $w_0 = w_L$, q_c increased significantly as I^*_L decreased below 0.12. This tendency is similar to that observed in the I_L–q_c relation of the treated clay with $w_0 = w_L$, as shown in Fig. 2. The two relations were similar even though I^*_L was calculated using the w_L and w_P of Ao clay instead of those of the treated clay; this might be because the A_{PS} of the PS ash was relatively small. However, the similarity between the two relations emphasized the importance of considering the water absorption performances of PS ash in evaluating the cone index development of clay treated by PS ash.

Table 3. Water absorption performance of PS ash, W_{ab}

Curing period	3 h	3 d	7 d	28 d
W_{ab} (%)	53.3	107.8	109.4	109.4

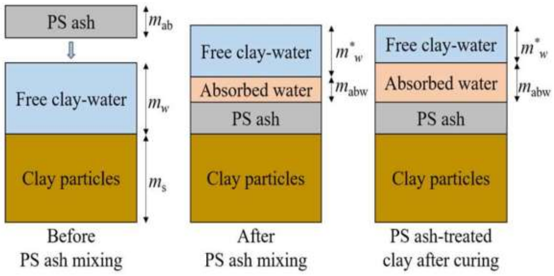

Figure 3. Absorption of free water by PS ash in clay

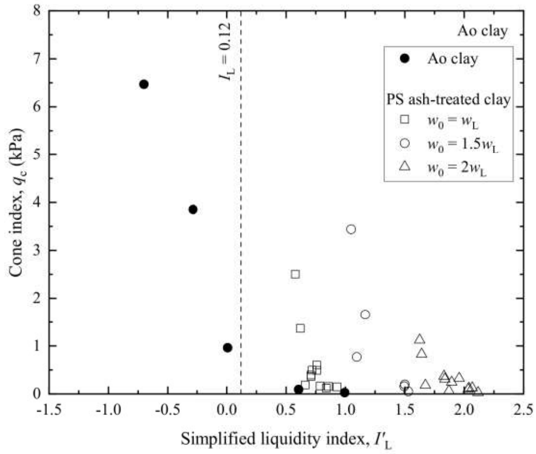

Figure 4. $q_c - I'_L$ of PS ash-treated clay

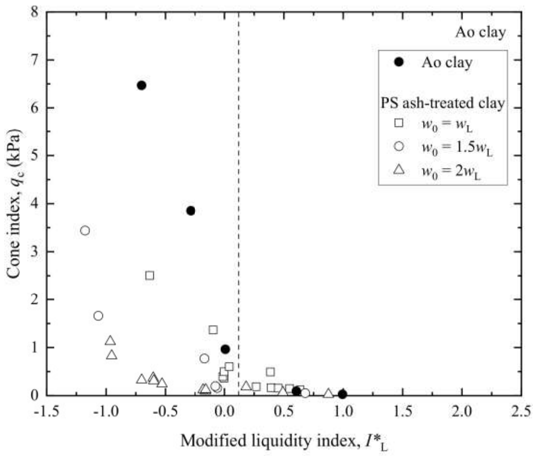

Figure 5. $q_c - I^*_L$ of PS ash-treated clay

5. CONCLUSIONS

Based on test results, it was discovered that the increase in the q_c of the treated clay is reasonably explained by the change in its quasi-liquidity index, I^*_L, which was calculated based on w^*. These findings suggest that if the W_{ab} of a PS ash for a specific curing period is evaluated and the free water content of the treated soil is calculated using W_{ab}, then the q_c of the treated soil can be assessed based on the modified water content w^*.

REFERENCES

Phan, N. B., Hayano, K., Mochizuki, Y., Yamauchi, H., (2021): Mixture design concept and mechanical characteristics of PS ash–cement-treated clay based on the water absorption and retention performance of PS ash, *Soils and Foundations* (in Press).