STRENGTH DEVELOPMENT MECHANISM IN DIFFERENT TYPE OF PAPER SLUDGE ASH-BASED STABILIZERS TREATED SOIL DUE TO TWO-STAGE CURING METHOD

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1. INTRODUCTION

Construction-generated soils have been recycled worldwide in construction projects. However, construction-generated soils often have negative characteristics for use as geomaterials in construction projects for their high fines content, high water content, and difficulty in compaction. Therefore, construction-generated soils are commonly treated through the addition of stabilizing agents such as cement or quicklime to improve their characteristics, which can sometimes result in financial and environmental problems. Soil stabilization using paper sludge ash-based stabilizers (PSASs) has also been developed recently to overcome these problems. PSASs can be produced by insolubilizing heavy metals in original paper sludge (PS) ash particles, which is waste generated by the incineration of PS discharged from paper mills. The surface shape of the PS ash particles has a porous structure with many complex irregularities and voids. Owing to this characteristic, PS ash can absorb and retain excess water construction generated soils. Moreover, scholars have reported that the water absorption and retention performance of PSASs increase with curing (Phan et al., 2021). This paper aims to investigate the effect of curing condition and curing environment on strength characteristics of PSAS-treated soils using two types of PSASs with different chemical compositions.

2. CONVENTIONAL LABORATORY MIXTURE DESIGHN

Fig. 1 shows the conventional flow of the laboratory mixture design for treating construction-generated soil with cement-based stabilizer. If compaction is performed during construction, primary curing is conducted on a soil–cement mixture, and subsequently, the mixture is crumbled. Thereafter, the crumbled mixture is immediately compacted, followed by secondary curing. The compacted specimen is subjected to mechanical tests, after the second curing step. Previous studies have reported that the strength characteristics of construction-generated soils treated with cement or lime are strongly affected by primary and secondary curing conditions. In addition, the “crumbling” is considered a disturbance to the treated soils. Such disturbances are known to reduce the strength of the treated soils. Therefore, it has been empirically recommended that the primary curing of cement- or lime-treated soils should be as short as possible, followed by crumbling and prompt compaction for solidification in secondary curing. Meanwhile, the effects of two-stage curing on PSAS-treated soils may differ from those of cement-treated soils. This problem has not been investigated in detail.

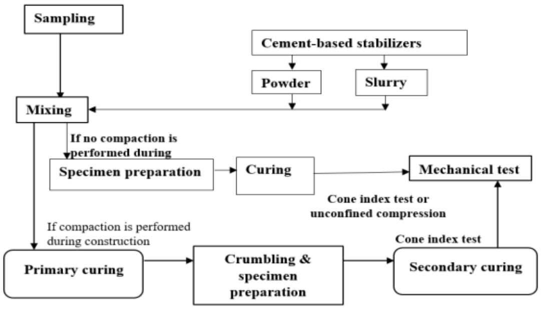

Fig.1 Conventional flow of laboratory mixture design (revised from Public Works Research Institute, 2013)

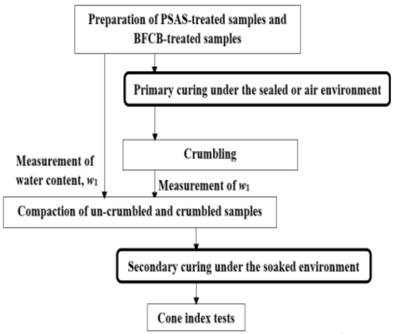

Fig. Sample preparation flow

Table 1 Curing conditions

Primary curing period (t_1) and environment	Secondary curing period (t_2) under the soaked environment	Total curing period (t=t_1+t_2)
Not implemented	1,3,7,14,28	1,3,7,14,27
1-day sealed curing	2,6,13,27	3,7,14,28
3-day sealed curing	4,11,25	7,14,28
1-day air curing	2,6,13,27	3,7,14,28
3-day air curing	4,11,25	7,14,28

3. MATERIALS, MIXTURE CONDITION, SPECIMEN PREPARATION

Ao clay, which is commercially available in Japan, was used in this study to represent the construction-generated soil. Two types of PSASs denoted as PSAS-N and PSAS-R were used. The type of original PS ash used differed between PSAS-N and PSAS-R. The ρ_s of PSAS-N and PSAS-R were 2.603 and 2.840 g/cm^3, respectively. The initial water content of Ao clay was adjusted to w_0 = 40.7%, which was the same its liquid limit (w_L). Subsequently, to prepare the PSAS-treated samples, we mixed PSAS-N or the PSAS-R with Ao clay at 20% for the dry mass ratio. Fig.2 shows the flow of the testing procedure for this experiment. Different curing conditions are listed in Table 1. In all PSAS-N-treated & PSAS-R-treated samples, the water content, w_1 of the treated sample was almost unchanged after primary curing under the sealed environment curing but decreased after primary curing under the air environment. Additionally, the w_1 of the PSAS-R treated samples did not decrease as significantly as those of PSAS-N treated samples because the PSAS-R-treated samples solidified more rapidly after mixing than the PSAS-R-treated samples.

Keywords: PSAS, Primary curing, Secondary curing, Cone index test, Crumbling
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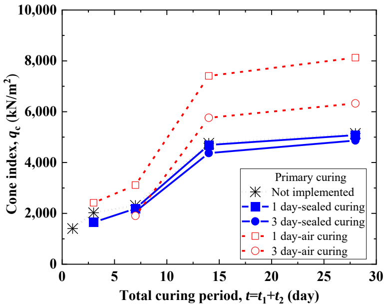
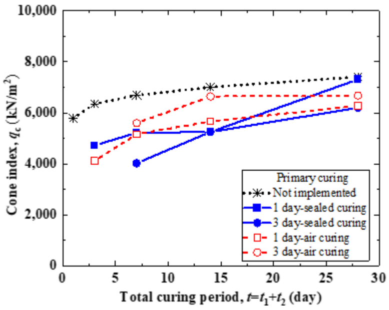
4. STRENGTH CHARECTERSTICS DURING CURING

Fig.3 shows the relationships between the cone index (q_c) and total curing period (t) of the PSAS-N-treated and PSAS-R-treated samples with or without primary curing. Regardless of the difference in the primary curing conditions, q_c increased with t; however, for the PSAS-R-treated samples, the q_c of the samples with primary curing under the sealed environment was significantly lower than that of the samples without primary curing. For the PSAS-N-treated samples, the difference in q_c between the two primary curing conditions was small. Fig.4 show the relationships between the water content w_1 and q_c obtained from the PSAS-N & PSAS-R. w_1 of the samples without primary curing and w_1 of the samples with sealed primary curing were relatively close and the q_c values of the latter samples were lower than those of the former samples. Fig.5(a) shows the scenario in which the strength loss due to crumbling was small, as for the PSAS-N-treated samples, whereas Fig.5(b) shows the scenario in which the strength loss due to crumbling was large, as for the PSAS-R-treated samples. It is known that in many scenarios, the strength of soil immediately after compaction is maximized when it is compacted at a water content that is slightly less than w_{opt}. Meanwhile, when immersed in water, the strength of soil compacted at or near w_{opt}, or slightly higher than w_{opt}, is often maximum. When the w_1 of the PSAS-N-treated samples or PSAS-R-treated samples after air primary curing approached w_{opt} at compaction, the q_c of the soaked samples was expected to be maximized. Therefore, as shown in Fig.5(a), when the strength loss owing to crumbling was small, q_c could be higher than that of the samples without primary curing. This condition was applied to PSAS-N-treated samples. However, as shown in Fig.5(b), when the strength decrease due to crumbling was significant, q_c could be lower than that of the samples without primary curing, although q_c increased from those of the samples with sealed primary curing. This condition applied to the PSAS-R-treated samples.

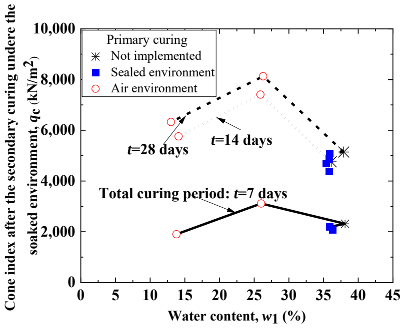


a) PSAS-N-treated samples

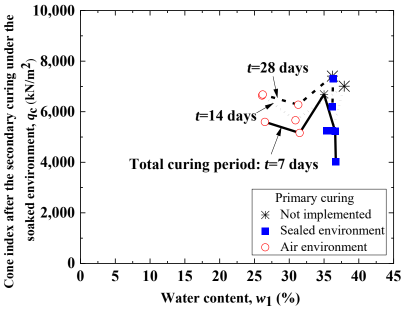


b) PSAS-R-treated samples

Fig. 3 Relationships between q_c and t

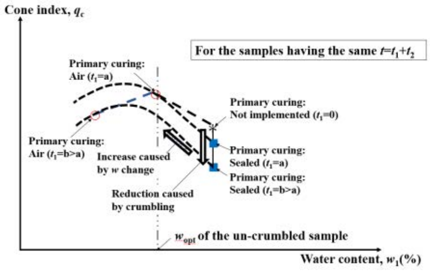


a) PSAS-N-treated samples

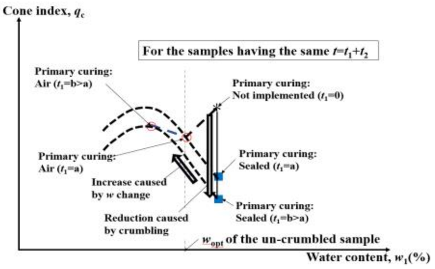


b) PSAS-R-treated samples

Fig. 4 Relationship between w_1 and q_c



a) PSAS-N-treated samples



b) PSAS-R-treated samples

Fig.5 Schematic image of the mechanism for the change in cone index of PSAS-treated samples due to crumbling and change in water content

5. Conclusion

In this study, the effects of primary curing conditions and subsequent crumbling on the strength characteristics of PSAS-treated soils were investigated using two types of PSASs. The cone index tests suggested that the cone index of the PSAS-treated samples with primary curing became higher or lower than that of the samples without primary curing, depending on the primary curing environment, number of curing days, and type of PSAS. The difference was considered to be caused by the combined effects of "strength reduction due to crumbling," and "strength increase due to water content reduction at compaction."

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