Expansion characteristics of lightweight foamed grout with foaming agent contents

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ABSTRACT

Road subsidence related to cavities sometimes occurs in urban areas in Korea, and local governments have been investigating the distribution of cavities which lead to the development subsidence to prevent disasters. To fill the empty spaces, adequate materials are required. This study presents the expansion characteristics of lightweight foamed grout developed with the intention of improving cavity filling. To estimate the theoretical expansion ratio, the unit weights at slurry and expanded states are measured. As the foaming agent contents increase, the unit weights at slurry states decrease slightly, while those at expanded states decrease rapidly and then converge on a certain value. The theoretical expansion ratio estimated from the two different types of unit weights first increases with an increase in the foaming agent content and then stabilizes. Compared to the measured expansion ratio, the error of theoretical expansion ratio is about 10 to 15%. Considering the difference between the theoretical and measured expansion ratios, the cavities may be fully filled with lightweight foamed grout.

Keywords: lightweight foamed grout, foaming agent, unit weight, expansion ratio

1 INTRODUCTION

Underground cavities sometimes occur in urban areas in Korea and, cause road subsidence or pavement to collapse. Many local governments in Korea have investigated the distribution of cavities to prevent the potential man-made disasters, and adequate materials need to be developed for filling the underground cavities.

Controlled low-strength material (CLSM) has been widely used for the backfill of narrow trenches because of its high flowability and low compressive strength (Blanco et al. 2014; Byun et al. 2016). However, the CLSM may have shrinkage characteristics related to the hydration process of cementitious materials, and thus, the underground cavities are difficult to fill using CLSM.

Lightweight foamed grout (LFG) was developed by Han et al. (2018) to fill cavities based on its volume expansion characteristic. Similar to CLSM, LFG has material characteristics of high flowability and low long-term compressive strength. This study presents the expansion characteristics of LFG to evaluate the effect of foaming agent content.

2 LIGHTWEIGHT FOAMED GROUT

The LFG used in this study was composed of ordinary Portland cement (OPC), foaming agent, and water. The specific gravities of OPC and foaming agent are 3.14 and 2.21, respectively. The chemical components of the OPC and foaming agent are summarized in Table 1. The OPC consists mainly of CaO (61.6%), SiO_2 (18.8%), and 4 ~ 5% of MgO, Al_2O_3, and Fe_2O_3. The foaming agent consists of SiO_2 (60.4%), Al_2O_3 (20.5%), and 1 ~ 6% of NaO, CaO, Fe_2O_3, and MgO. The foaming agent includes aluminum powder to expand the volume of the LFG.

Table 1. Chemical components of cement and foaming agent.

Material	Cement	Foaming agent
SiO_2 [%]	18.8	60.4
Fe_2O_3 [%]	4.10	2.75
Al_2O_3 [%]	4.26	20.5
CaO [%]	61.6	3.31
MgO [%]	4.82	1.67
K_2O [%]	1.06	0.95
Na_2O [%]	1.35	5.13
lg. loss [%]	2.70	5.71

Aluminum powder is thinly coated with Al_2O_3 in air conditions. When aluminum power is in alkali conditions such as cement paste, the Al_2O_3 film disassembles as indicated in Eq. (1). The exposed aluminum reacts with $Ca(OH)_2$ in alkali conditions according to Eq. (2). The reacted aluminum produces hydrogen gas and expands the volume of LFG (Hwang and Song 1997; Aubert et al. 2004; Wang et al. 2010, Shon et al. 2018).

$$Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2Al(OH)_4^- \quad (1)$$

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O + 3H_2\ (g) \quad (2)$$

In this study, the LFG was blended with a 1.0 water-cement ratio and some foaming agent. The mixing procedure was controlled to maintain the uniformity of the expanded LFG samples. First of all, water and foaming agent are mixed using a stirrer for 90 seconds. After mixing, the cement was added and the mixture was blended for 60 seconds. To evaluate the expansion characteristics depending on the foaming agent contents, the contents of the foaming agent were changed to 0, 0.4, 0.8, 1.6, 2.0, 2.4, 3.2, and 4.0 of the total weight of water and cement.

3 EXPERIMENT AND RESULTS

3.1 Unit weight

During curing, the mixed LFG changes from slurry to expanded states. The unit weights at slurry and expanded states of LFG were evaluated according to the foaming agent contents. The unit weights at slurry states of LFG were estimated using a cylindrical mold with a 140 mm diameter and 130 mm height according to ASTM D6023 (2016). Note that the dimensions of the mold recommended by ASTM D6023 is different from those of the mold used in this study. The unit weights at expanded states were also estimated from the cured samples in the same mold for 1 day.

The unit weights at slurry and expanded states are plotted in Fig. 1. At slurry states, the unit weight of LFG without foaming agent was 1.51 t/m^3, and the unit weights of the LFG decreased slightly with an increase in the foaming agent contents. At expanded states, the unit weights decreased rapidly up to 1.6 of foaming agent content and stabilized at 0.8 t/m^3.

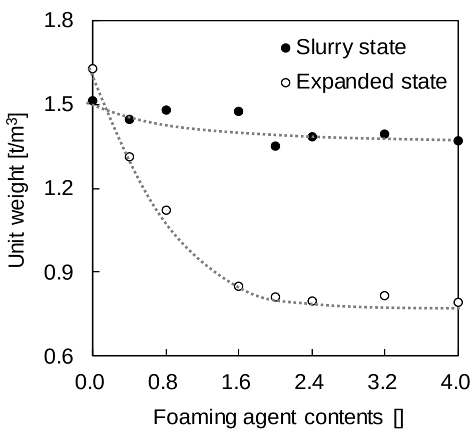

Fig. 1. Variation in unit weight of lightweight foamed grout with foaming agent content

3.2 Expansion ratio

In this study, theoretical expansion ratios are suggested using the unit weights at slurry and expanded states. The theoretical expansion ratios are defined as represented in Eq. (3) assuming that the weights (W_s and W_e) of material components at slurry and expanded states are maintained.

$$V_e / V_s = (W_e / \gamma_e) \ / \ (W_s / \gamma_s) = \gamma_s / \gamma_e \quad (3)$$

The estimated expansion ratios are shown in Fig. 2. The volume of LFG at slurry state without the foaming agent shrinked to 92.8% for a day. However, all the LFG containing foaming agent expanded to 110.0% at 0.4 of foaming agent content and 132.2% at 0.8. At the foaming agent contents greater than 1.6, expansion ratios of 170% were converged.

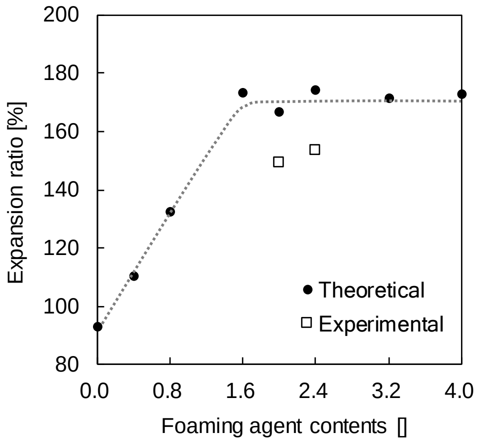

Fig. 2. Variation in expansion ratio of lightweight foamed grout with foaming agent content

The expansion ratios were also measured in the expansion tests as shown in Fig. 3 to compare with the theoretical expansion ratios at 2.0 and 2.4 of foaming agent contents.

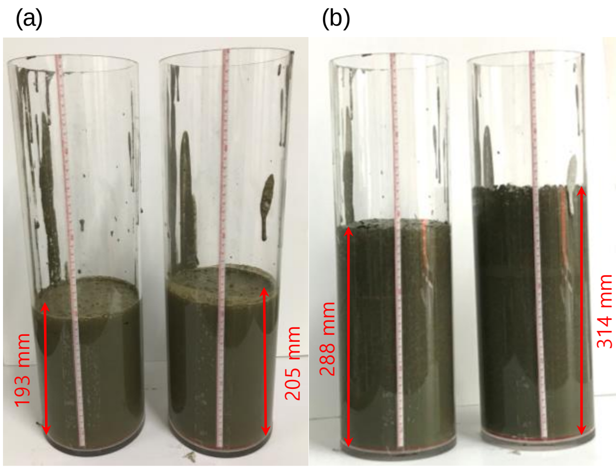

Fig. 3. Expansion tests for 2.0 (left) and 2.4 (right) of foaming agent contents: (a) at slurry state; (b) at expanded state

The two expansion ratios at foaming agent contents of 2.0 and 2.4 were 149.2% and 153.2%, respectively. Compared to the measured expansion ratio, the errors of theoretical expansion ratios were 11.6% and 13.6%. Considering the greater expansion ratio, LFG can be effectively used for filling underground cavities.

3 CONCLUSIONS

Underground cavities occurring in urban areas have potential for man-made disasters. One of the solutions to fill underground cavities is LFG which expands in volume with curing time. In this study, the unit weights of LFG at slurry and expanded states were measured. To evaluate expansion characteristics, the expansion ratios were calculated from the unit weights, and measurements of the expansion tests.

The unit weights at slurry states slightly decreased, whereas the unit weights at expanded states dramatically decreased and settled at foaming agent contents greater than 1.6. The theoretical expansion ratios increased with foaming agent contents up to 1.6 and thereafter plateaued. The theoretical ratios were larger than the experimental ratios with errors within 15%. Therefore, the theoretical expansion ratio can be effectively used for the estimation of LFG mixing quantity.

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