Thermal conductivity of controlled low strength material (CLSM)

Tan Manh Do[1], Young-Sang Kim[2*], Gyeong-O Kang[1], Thien Quoc Tran[1]

[1]Department of Civil and Environmental Engineering, Chonnam National University, Yeosu, Jeollanam-do 59626, Korea
[2]Department of Civil Engineering, Chonnam National University, Yongbong-ro 77, Buk-gu, Gwangju 61186, Korea
* geoyskim@jnu.ac.kr

Abstract

Thermal conductivity of controlled low strength material (CLSM) is investigated in this study. In order to do this, the pressure plate extractor apparatus (SWC-150) was modified by coupling with a single thermal needle probe. In the experimental program, thermal conductivity, the degree of saturation were measured simultaneously by the modified apparatus. As a result, linear relationships between thermal conductivity and degree of saturation of the proposed CLSM mixtures were observed. Moreover, it was found that an increase of an excavated soil working as filler in CLSM could lead a relative improvement in thermal conductivity.

Brief introduction, methodology and key results

The American Concrete Institute (ACI) defines CLSM as a self-leveling, self-compacting, and cementitious material primarily used to replace conventional backfill soil and structural fillings that result in unconfined compressive strengths of 1,200 psi (8.3 MPa) or less (ACI 229, 1999). CLSM is not considered as a type of low-strength concrete, but rather as a structural backfill. During the past decade, various kinds of CLSM have been developed by confirming its specifications (e.g., flowability, bleeding, fresh density, initial setting time, unconfined compressive strength, corrosivity, and heavy metals) reported in ACI 229R, (1999). Several successful applications of CLSM have been reported, such as backfills, structural fills, pavement bases, and void filling. However, there has been very little attention paid to the research aspect of thermal conductivity of CLSM that can be used as heat transfer medium. Lee et al., (2012) and Simon et al., 2016 mentioned the use of CLSM as a backfill material for underground power cables. Lee et al., (2012) attempted to develop a CLSM, using coal ash (e.g., fly ash, Pond ash) as a primary ingredient. Simon et al., (2016) attempted to develop CLSM from soil excavation, clay (if necessary), cement, and water. Graphite and plasticizer were suggested in their study to enhance the thermal conductivity of CLSM for a possible reduction of thermal damage for underground power cables. More recently, Kim et al., (2018) opened a new chapter in the research of CLSM, applying to geothermal field. In order to be used as the heat transfer medium (i.e., probably above or below ground water table), the relationship between thermal conductivity and degree of saturation of CLSM should be exploded. It is well known that degree of saturation has a significant influence on thermal conductivity of general soils. However, research of this effect on CLSM has never been closely taken into consideration.

The main purpose of this study is to evaluate the thermal conductivity of controlled low strength materials (CLSM) as a function of degree of saturation by using the modified pressure plate extractor apparatus. CLSM was produced using pond ash, excavated soil, very little cement, and water.

In the experimental program, control mixture was produced with cement, fly ash, pond ash, and water. Subsequently, excavated soil was substituted for pond ash in amounts of 10, 20, 30, and 40% replacement by weight. Thermal conductivity test conforming to ASTM D5334 was conducted simultaneously with the 28-day unconfined compressive strength test. In the thermal conductivity test, the thermal needle probe used consists of a heating element and a temperature measuring element and is inserted into the CLSM specimen. In this study, the thermal conductivity of the proposed CLSM was measured with respect to degree of saturation by using the modified pressure extractor apparatus. The modified pressure extractor apparatus was designed by coupling the original pressure plate extractor apparatus (SWC-150) with the single thermal needle probe. The tube fitting male connector CMC 6-8N was used to link the body of SWC-150 with a thermal needle for a prevention of pressure air leaks.

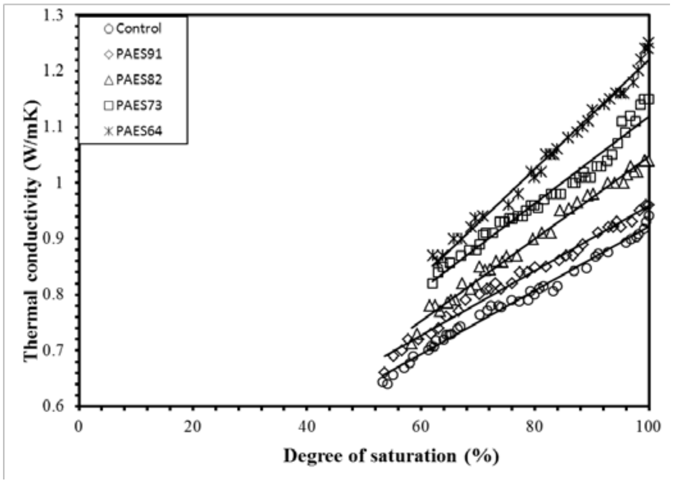

Fig. 1: Relationship between degree of saturation and thermal conductivity of the proposed CLSM

Fig. 1 shows the thermal conductivity plotted against the degree of saturation for the proposed CLSM. As a result, thermal conductivity decreased linearly as the degree of saturation declined. Thermal conductivity of Control, PAES91, PAES82, PAES73, and PAES64 varied in ranges of 0.64-0.94 W/mK, 0.66-0.99 W/mK, 0.71-1.04 W/mK, 0.82-1.15 W/mK, and 0.87-1.25 W/mK, respectively. In addition, it is worth noting that the replacement of excavated soil to pond ash led to an enhancement in thermal conductivity, regardless of the degree of saturation. The majority of improvement in thermal conductivity can be observed under saturated state. The saturated thermal conductivities of Control, PAES91, PAES82, PAES73, and PAES64 were 0.94 W/mK, 0.99 W/mK, 1.04 W/mK, 1.15 W/mK, and 1.25 W/mK, respectively. The thermal conductivity was enhanced by 5.32% (PAES91), 10.64% (PAES82), 22.34% (PAES73), and 32.98% (PAES64) at the excavated soil replacements of 10%, 20%, 30%, and 40%, respectively.

This finding that presents the thermal conductivity as a function of the degree of saturation of CLSM plays a key role in the field when CLSM is used as backfill material for underground power cables. In this case, most portion of CLSM is above groundwater table and the thermal conductivity of this material should be considered as a function of degree of saturation rather a single thermal value (i.e., unsaturated or dried thermal conductivity) in the conventional design.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2018R1A2B6007567).

References

ACI 229R, "Controlled Low Strength Materials (ACI 229R-99)," 1999

Lee, S.J., Lee, J.H., Cho, H.S., Chun, B.S., 2012. An Experimental Study on Thermal Conductivity of Controlled Low Strength Materials with Coal Ash. KSCE journal (Korean). 32(3): 95–104

Simon, J., Middendorf, B., Friedenberg, S.K., 2016. Thermal conductivity of controlled low strength materials (flowable fill). The 4th International Symposium on Ultra-High Performance Concrete and High Performance Materials, Kassel, Germany

Kim, Y.S., Do, T.M., Kim, M.J., Kim, B.J. and Kim, H.K., 2018. Utilization of by-product in controlled low-strength material for geothermal systems: Engineering performances, environmental impact, and cost analysis. Journal of Cleaner Production. 172 (20), 909–920