Engineering properties of controlled low-strength material (CLSM) as an alternative fill material

Thanakorn Chompoorat[1*], S. Likitlersuang[2], and P. Jongvivatsakul[3]

[1] Associate Professor, Department of Civil Engineering, School of Engineering, University of Phayao, Phayao Thailand.
[2] Professor, Centre of Excellence in Geotechnical and Geoenvironmental Engineering, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok Thailand.
[3] Assistant Professor, Innovative Construction Materials Research Unit, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok Thailand.

ABSTRACT

Controlled low-strength material (CLSM), is a self-compacting material usually consisted of binder (cement and/or fly ash), fine aggregates (sand), water and admixture. This paper aims to investigate the engineering properties of CLSM utilising fly ash from electricity power plant as fill materials. The CLSM specimens were mixed by varying the proportion of Portland cement type I, silica sand, fly ash, water and air-entraining agent. The laboratory tests including flow, setting time, air content, and breeding were performed to characterise the properties of fresh CLSM. The engineering properties of hardened CLSM were investigated by means of California bearing ratio, unconfined compressive strength and resilient modulus tests. In addition, the dynamic moduli from shear wave velocity measurement were carried out by a free–free resonant method. The result shows that the unconfined compressive strength at 28 days curing of CLSM can be controlled in the range of 1–10 MPa to serve for the requirement of different activities of fill material. Additionally, the result also suggests the resilient modulus and shear wave velocity of CLSM for pavement and geotechnical applications.

Keywords: Controlled low-strength material; fly ash; unconfined compressive strength; resilient modulus; shear wave velocity

1 INTRODUCTION

Controlled low-strength material (CLSM) is defined by the ACI Committee 229 (ACI, 1999) as a self-compacting cementitious material that is in a flowable state at the time of placement and has a specified compressive strength of 8.3 MPa or less at 28 days. CLSM mixture usually contains cement, sand, fly ash and chemical additive. Recently, CLSM can be used to replace crush rock base materials (Chompoorat, 2018). Since CLSM may be more cost-effective as its high workability and self-leveling lead to reduce labor cost (Ramme, 1997) especially in some areas where the proper crush rock base materials (i.e., California bearing ratio (CBR) ≥ 80%) are rare to find. In addition, CLSM containing low cement content can possibly be excavated after use.

Lately, several researches have been conducted regarding the use of various industrial by-products in the production of CLSM. Large amounts of by-product materials such as fly ash, recycled concrete aggregate, recycled fine aggregates, and blast furnace slag were utilised to lower the cost and to ensure the required maximum compressive strength (Naik et al., 2006; Achtemichuk et al., 2009; Miren et al., 2013; Chompoorat, 2018). It is known that the application of fly ash in CLSM provides many advantages, such as good flowability, reduced segregation and bleeding, and in numerous cases, a reduced material cost (Chompoorat, 2018). Additionally, fly ash base may continue to increase its strength for a long time due to pozzolanic reactivity. In Thailand, the fly ash is regarded as the waste material. The main supplier of fly ash is an electricity generating plant from lignite known as the Mae Moh Power Plant owned by Electricity Generating Authority of Thailand (EGAT).

This study presents the engineering properties of CLSM mixtures produced on Mae Moh fly ash. The results were obtained from the highway standard laboratory tests such as the CBR test, the unconfined compression (UC) test, the resilient modulus (M_R) test, and the determination of dynamic modulus from free–free resonant (FFR) method.

2 MATERIALS AND METHODS

2.1 Materials

In this study, CLSM mixtures consist of Portland cement type I, class C fly ash, sand, water, and air-entraining admixture. The class C fly ash obtained from EGAT. Physical and engineering properties of cement, fly ash, and sand were tested and reported in

Chompoorat et al. (2018). The air-entraining admixture was applied to improve flowability and control low strength of mixture.

2.2 Specimen Preparation

The CLSM mixtures were produced according to the specification of ASTM D 4832 (2010). The specimen of 155.5 mm diameter and 113.5 mm height was prepared for CBR test by filling in the mixture to the PVC cylindrical mould. For the UC test, M_R test, and FFR test, the specimens were prepared using a PVC mould of 56 mm diameter and 112 mm height. The samples were forced out from the moulds after 24 hours curing. All the samples were wrapped using plastic wrap until it reached the specified different curing times as planned. The mixture proportions used in this research are listed in Table 1.

Table 1 Mixture proportions

Mix no.	Binder (kg/m³)	Water (L/m³)	Sand (kg/m³)	Air-entraining admixture (% by Vol.)
1	300	200	1,400	0.004
2	450	190	1,365	0.004
3	600	200	1,330	0.004
4	280	240	1,500	0.004
5	265	240	1,500	0.004
6	240	240	1,500	0.004
7	265	240	1,500	0.002

2.3 Experimental Programme

The flowability of the CLSM mixtures were determined by slump flow and marsh cone tests according to ASTM C1611 (2014) and ASTM C939 (2016), respectively. Additionally, the setting time, air content and breeding of CLSM mixtures were also measured following ASTM C403 (2016), ASTM C231 (2017) and ASTM C232 (2014), respectively. For hardened CLSM mixtures, the laboratory tests including CBR test (ASTM D1883, 2016), UC test (ASTM D2166, 2016), M_R (AASHTO T307, 2007), and FFR test were carried out through this research, as summarised in Table 2.

Table 2 Experimental programme

Test	Curing time (days)	Condition
CBR	1, 4, 7	Unsoaked
	4	Soaked
UC	7, 28, 60	Dry
M_R	7	Dry
FFR	1, 4, 7	Dry

For the UC test, all samples were set up at the universal testing machine (UTM) and compressed under static condition at a strain rate of 1.0 %/min. For the M_R test the dynamic UTM was carried out following AASHTO T307. To find the dynamic modulus for estimating the response under small strain, FFR method were carried out. In this study, a CLSM specimen is hang on a frame in the direction of horizontal and suspending it with tendon to approach free boundary conditions as shown in Fig.1. An accelerometer is placed in contact with one end of the specimen to measure vibrations, while the other end is impacted with a light hammer. The interpretation of E_0 and G_0 is calculated based on the following formulas.

$$E_0 = \rho v_p^2 = \rho(2Lf_L)^2 \quad (1)$$

$$G_0 = \rho v_s^2 = \rho(2Lf_T)^2 \quad (2)$$

where ρ is the bulk density, L is the length of the specimen, f_L is the longitudinal resonant frequency, f_T is the torsional resonant frequency, v_p is the longitudinal (compressive) wave velocity and v_s is the torsional (shear) wave velocity.

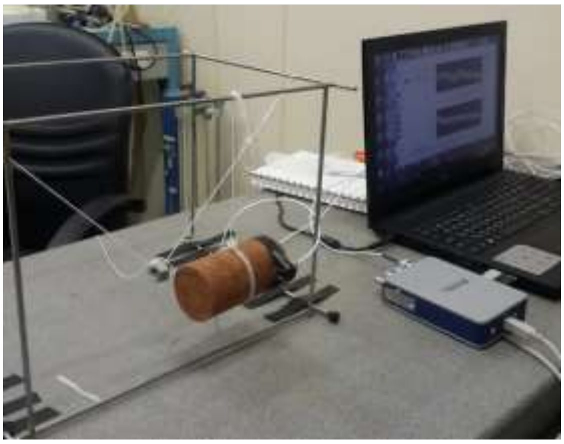

Fig. 1 FFR test set up

3 RESULTS AND DISCUSSIONS

3.1 Properties of fresh CLSM

The properties of fresh CLSM were conducted to determine the flow properties including the slump and flow tests, the setting time and bleeding tests as well as unit weight and air-content measurements. The results of fresh CLSM properties are summaried in Table 3.

Table 3 Properties of fresh CLSM

Mix no.	Flow Slump flow (mm)	Flow time (sec)	Setting time (hr)		Breeding		Unit weight (kg/m³)	Air content (%)
			Stiffening	Initial	hr	%		
1	655	114	4.30	7.35	2.4	6.77	1,785	17.0
2	650	117	5.45	9.25	2.4	8.16	1,870	14.0
3	655	71	6.35	11.05	4.1	8.42	1,912	12.0
4	640	Block	5.25	10.55	2.1	11.51	1,847	14.5
5	650	Block	5.40	10.45	2.4	11.51	1,843	14.0
6	660	Block	4.55	10.50	2.4	14.21	1,844	14.0
7	680	Block	5.25	9.10	3.1	14.20	1,892	12.0

3.2 CBR Test

Fig. 2 illustrates the CBR values obtained from all CLSM mixtures. The results show that the CBR increases with time and increases when W/B decreases. For soaked samples, the CBR values is significantly lower than the unsoaked samples at the same curing day. Based on the Thailand's Department of Highways (DOH) standard, the CBR value of crush rock base material must be greater than 80%; therefore, the unsoaked CBR value of CLSM mixture at 7 days curing can meet the standard.

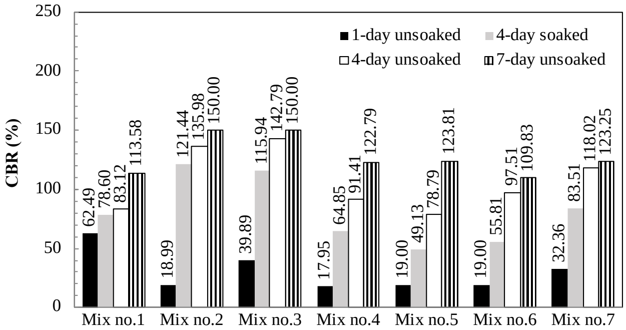

Fig. 2 Result of CBR tests (Bamrungpong et al., 2017)

3.3 UC Test

The results from the UC test of the CLSM mixture are shown in Fig. 3. In general, the unconfined compressive strength (UCS) significantly increased with curing time, especially within the first 7 days due to cementation. However, the required UCS for re-excavation recommended by ACI 229 (2013) is 8.31 MPa. All mixes at 28 days and solely the mix no. 4 to 7 at 60 days satisfy this requirement. Based on the standard of Thailand Department of Highways (DH-S 206/2532, 1989; DH-S 204/2556, 2013), the cement-treated soil should pass the requirement of UCS at 7 days curing of 1.72 MPa. In this study, the CLSM mixes no. 1, 2, and 3 shall satisfy the strength requirement.

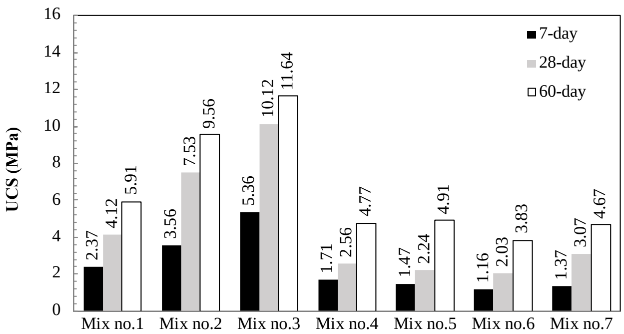

Fig. 3 Result of UC tests (Bamrungpong et al., 2017)

3.4 M_R Test

Fig. 4 shows the M_R test results at different confining stress and deviator stress at 7 days curing. In general, the M_R values decrease with an increase in deviator stress. Since the M_R is stress dependent parameter, which is more influenced by deviator stress rather than confining stress (Puppala et al., 2011; Chompoorat, 2012; Bamrungpong et al., 2017; Chompoorat et al., 2018). Comparing among all mixes, the average M_R value of the mix no. 3 is the highest one (850 MPa) while the mix no. 6 is lowest one (554 MPa). It is because that the mix no. 3 and the mix no. 6 contain the lowest W/B ratio and the highest W/B ratio, respectively.

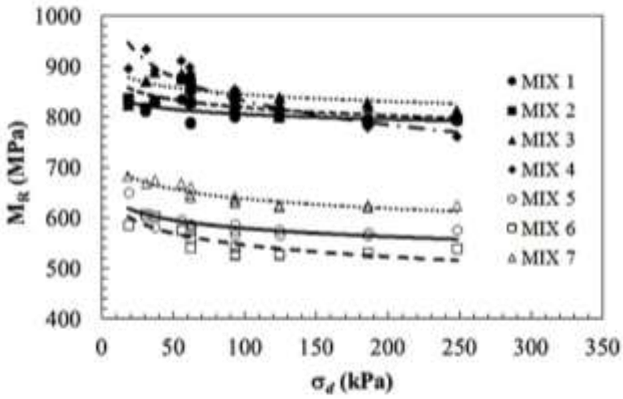

Fig. 4 Results of M_R test (Bamrungpong et al., 2017)

3.5 FFR Test

The FFR method helps to monitor the hydration and pozzolanic process that causes the strength increase as a result of a microstructure formation. The velocity increasing over time can imply an increase in material stiffness due to hydration and pozzolanic reactions.

The E_0 and G_0 can be calculated from the longitudinal velocity and torsional velocity in Eqs. 1 and 2, respectively. Figs. 5 and 6 show the values of E_0 and G_0 for each CLSM mixtures at different curing time. The result show that the increase of dynamic modulus, which corresponds to the increase in the resonance wave velocity, indicated that cement and fly ash is initially set (7 days curing). Initial setting is important in pavement projects because the road is usually expected to be open for service as soon as possible.

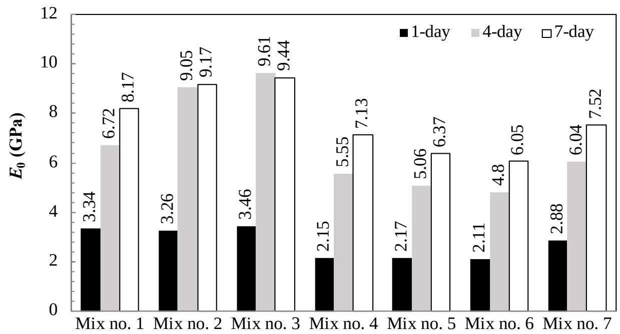

Fig. 5 Result of E_0 from FFR tests

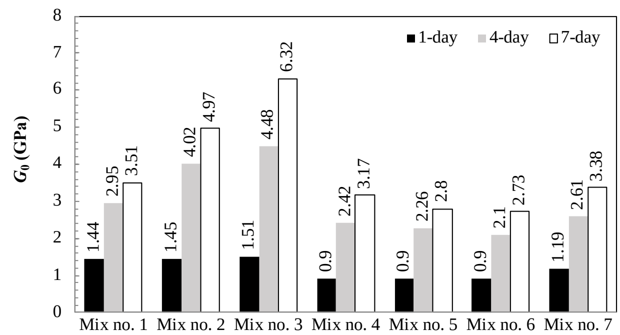

Fig. 6 Result of G_0 from FFR tests

Comparing among all mixtures at 7 days curing, the E_0 and G_0 values of mix no. 3 is the highest ones (9.44 GPa and 6.32 GPa) while the mix no. 6 shows the lowest values (6.05 GPa and 2.73 GPa) as expected from the W/B ratios.

4 CONCLUSION

This research studies engineering properties of controlled low-strength material (CLSM) aiming to use as pavement base material. The results found that the CLSM base yielded significantly higher in mechanical properties even than the conventional crush rock base. Some key concluding from the study can be drawn as follows.

1. The CBR results after 4 days are over 80% and the UCS value at 7 days curing of mixes no. 1 to 3 are greater than 1.72 MPa, which pass the requirement of cement-treated base material.

2. The M_R tests at various confining and deviator stresses exposed a consistent agreement with the UCS results. The average of M_R values for CLSM mixtures are in the range of 554 – 850 MPa. This value is significantly higher than the MR of crush rock base.

3. In this paper, the FFR method was adopted to determine the small-strain stiffness moduli of CLSM. As the natural frequency of a specimen is mostly dependent on the fundamental properties of the material, the FFR test is able to the determination of those properties without damaging the sample.

ACKNOWLEDGEMENTS

This research was funded by the annual government statement of expenditure fund from the University of Phayao Grant No. RD61036. The second author would like to acknowledge the Thailand Research Fund Grant No. DBG-6180004 and the Ratchadapisek Sompoch Endowment Fund (2019), Chulalongkorn University (762003-CC).

REFERENCES

AASHTO T307 (2007). Standard method of test for determining the resilient modulus of soil and aggregate materials, American Association of State Highway and Transportation Officials, Washington, D. C.

Achtemichuk, S., Hubbard, J., Sluce, R., Shehata, M.H. (2009). The utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement, Cement and Concrete Composites, 31(8), 564–569. DOI: 10.1016/j.cemconcomp.2008.12.011

ACI Committee 229 (1999). Controlled low strength materials (ACI 229R), American Concrete Institute, Farmington Hill, Michigan, USA.

ASTM Designation C 231 (2017). Standard test method for air content of freshly mixed concrete by the pressure method, Philadelphia, USA. DOI: 10.1520/C0231_C0231M-17A

ASTM Designation C 232 (2014). Standard test methods for bleeding of concrete, Philadelphia, USA. DOI: 10.1520/C0232_C0232M

ASTM Designation C 403 (2016). Standard test method for time of setting of concrete mixtures by penetration resistance, Philadelphia, USA. DOI: 10.1520/C0403_C0403M-16

ASTM Designation C 939 (2016). Standard test method for flow of grout for preplaced-aggregate concrete (flow cone method), Philadelphia, USA. DOI: 10.1520/C0939_C0939M-16A

ASTM Designation C 1611 (2014). Standard test method for slump flow of self-consolidating concrete” Philadelphia, USA. DOI: 10.1520/C1611_C1611M-14

ASTM Designation D 1883 (2016). Standard test method for California Bearing Ratio (CBR) of laboratory-compacted soils, Philadelphia, USA. DOI: 10.1520/D1883-16

ASTM Designation D 2166 (2016). Standard test method for unconfined compressive strength of cohesive soil, Philadelphia, USA. DOI: 10.1520/D2166_D2166M-16

ASTM Designation D 4832 (2010). Standard test method for preparation and testing of controlled low strength material (CLSM) test cylinders, Philadelphia, USA. DOI: 10.1520/D4832-16

Bamrungpong, W., Chuejedton, N., Likitlersuang, S., Jongvivatsakul, P., and Chompoorat, T. (2017). A study of properties of controlled low – strength material made from fly ash utilized as pavement base material, Engineering Journal of Research and Development, 28(4), 15 – 26 (In Thai).

Chompoorat, T. (2012). Dynamic properties of cement treated clay, The Seventh Asian Young Geotechnical Engineers Conference (7AYGEC), Tokushima, Japan, 273-279

Chompoorat, T., Likitlersuang, S., and Jongvivatsakul, P. (2018) The performance of controlled low-strength material base supporting a high-volume asphalt pavement, KSCE Journal of Civil Engineering, 22(6), 2055 – 2063. DOI 10.1007/s12205-018-1527-z

Miren, E., Javier, A., Eugenia, P.M., and Alain, G. (2013). Use of recycled fine aggregates for Control Low Strength Materials (CLSMs) production, Construction and Building Materials, 44, 142–148. DOI: 10.1016/j.conbuildmat.2013.02.059

Puppala, A.J., Hoyos, L.R., and Potturi, A.K. (2011). Resilient moduli response of moderately cement-treated reclaimed asphalt pavement aggregates, Journal of Materials in Civil Engineering, 23(7), 990-998. DOI:10.1061/(ASCE)MT.1943-5533.0000268

Ramme, BW (1997). Progress in CLSM: continuing innovation, Concrete International, American Concrete Institute, 19(5), 32-33.

Naik T.R., Kraus R.N., Ramme B.W., Chun Y.M., and Kumar R. (2006). High-carbon fly ash in manufacturing conductive CLSM and concrete, Journal of Materials in Civil Engineering, 18(6), 743-746. DOI: 10.1061/(ASCE)0899-1561(2006)18:6(743)