Physical Modelling in Geotechnics

Field and laboratory tests of soil-cement columns with new eco binder

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ABSTRACT: This study investigates the stabilizing capacity of a new eco-binder: a mixture of cement (CEM), ground granulated blast-furnace slag (GGBS), and wood pellet fly ash (WA), hereby called wood ash binder (WAB), for improving the mechanical properties of Korean weathered soils (WS). With the development of this new binder, WAB, the possibility of reducing the use of high carbon base construction material for soil-cement columns and recycling byproducts of power plant fuel is explored. For this reason, the WAB's binding capacity at 5%, 15%, and 25% at optimum moisture content treatment on WS was evaluated through unconfined compressive tests at laboratory. Field tests of soil cement columns with the new WAB were also performed. Then after 28 curing days the cored specimen from the actual soil-cement columns were investigated to evaluate the field performance. The results of both laboratory and field tests in this study presents the compatibility of WA with CEM and GGBS at higher WAB contents (15% and 42.3% dosage rate). On top of that, significant cementation activity was observed due to the strength gain at the early and long-term stage of geopolymer strength developments. Thus, this study confirms the potential of the new eco-friendly binders as an alternative ground improvement material.

Keywords: wood pellet fly ash, soil-cement column, eco-friendly binders, unconfined compressive tests, field tests

1 INTRODUCTION

Climate change has caused severe impact on the world's ecosystem. Thus, the international community is gradually shifting to renewable energy sources rather than traditional fossil fuels. South Korean government, in particular, is now promoting domestic energy policies through the use of wood pellets for power plants (Fletcher, 2015; MOTIE, 2017a; 2017b; Wood Resources International, 2017; Proskurina et al. 2019;). This, wood pellets have low carbon content, which could help mitigate greenhouse gas emissions (Kim et al., 2021).

However, it is estimated that 3.5 million tons of ash from WA combustion are produced and dumped in landfills annually, which is higher than the coal ash combustion rate. Therefore, developing a recycling technology on WA in this emerging problem is necessary. This study aims to explore the potential binding effect on the mechanical properties of Korean weathered soils (WS) when mixed with WAB for both laboratory and field conditions for develop recycled an alternative binder for soil-cement mixing.

2 TESTING MATERIALS AND METHODS

Weathered granite soils are used as the natural host soil in this study. These soils are typically found in the mountainous geography of South Korea. According to AASHTO T294-92, WS is classified as Material Type 2 and one of the most preferred subgrade materials in practice. The wood pellet ash (WA) used in this study is discharged from Yeongdong Eco Power Plants Korea South-East Power Co. Ltd. (KOEN). Wood pellets undergo pyrolysis during energy production, then by-products are produced. The WA, in particular, is by-products recovered from the installed hybrid dust collector located at the top of the boiler. The WA particles have dry density of 2.31g/cm^3, fineness of 3350 cm^2/g, and pH of 12 or higher and typically dark gray. Table. 1 presents the geotechnical properties of WS1 and WA. The weathered soil WS1 is used for the laboratory tests. On the other hand, a commercial type 1 Portland cement is used. While GGBS are the by-products of a processed iron through a blast furnace. Table 2 presents the chemical properties of the binders.

Table 1. Properties of host soil and biomass ash.

Material	G_s	e_{max}	e_{min}	d_{50} (mm)	d_{10} (mm)	MDD (g/cm^3)	OMC (%)	USCS
WS 1	2.67	1.021	0.554	1.207	0.447	2.202	11.0	SP
WS 2*	2.67	-	-	0.335	0.091	1.589	15.3	SM
Wood pellet fly ash	10.0	-	-	15.347 x10^{-3}	2.636 x10^{-3}	-	-	-

Note: * = soil used in field test conducted by Zian Co. Ltd

Table 2. Chemical properties of binding materials.

Material	Blaine (cm^2/g)	G_s	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
WA	3350	2.31	23.25	6.6	3.81	27.8	3.21	3.47	16.64
C	3240	3.15	21.88	5.02	3.66	64.18	2.01	1.83	0.92
GGBS	3300	2.85	33.4	15.8	0.6	41.8	5.3	0.3	1.5

Note: C = cement; GGBS = ground granulated blast furnace slag; LOI = loss on ignition (WA is 6.82, C is 0.35 while GGBS is 0.3); LSF = lime saturation factor (WA is 0, C is 90.4 while GGBS is 1)

The dry WS were mixed at optimum moisture contents (OMC, from the results of compaction characteristics using ASTM D1557-12e1) to prepare compacted specimens using a laboratory mixer thoroughly for 1.5 to 2 minutes. Then the moist soil and dry binder (WAB composed of 20% cement, 30% GGBS and 50% WA) are mixed until homogenized (8 minutes). 50-mm-diameter and 100-mm-height specimens were compacted using an 8-mm-diameter tamping rod on a cylindrical split mold, with five layers producing a length to diameter (L/D) ratio of 2:1. Then the specimens were placed inside a covered bucket (filled with a small amount of water), wherein molds are not in direct contact with water (to prevent the specimens from drying) and cured at room temperature. A total of thirty-six specimens were compacted through the undercompaction method (5%, 15%, and 25% WAB stabilized WS) at 95% of relative compaction (R_c) at OMC. Unconfined compressive tests (UCT) were conducted (ASTM D2166:2006) to evaluate the unconfined compressive strength (q_u).

As for the field tests, Soil-WAB columns were installed by deep cement mixing (DCM) method at a test site located at Zian Co. Ltd, Boryeong, Chungnam, South Korea. The Soil-WAB columns were installed down to weathered soil with natural water contents of 13.4%) at a depth of 48 m as shown in Fig. 1. The basic properties of the weather soil at the field testing site (WS2) are listed in Table 1.

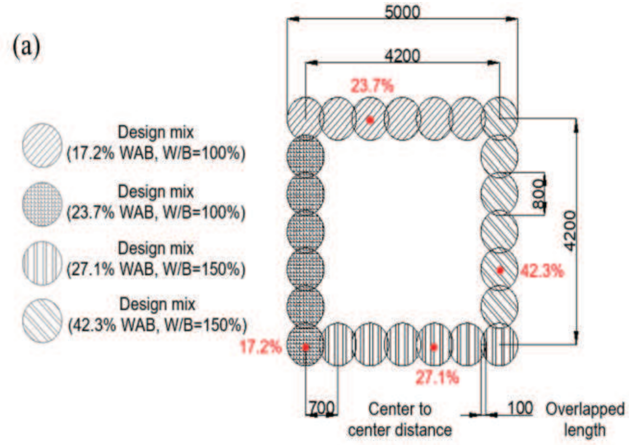

Fig. 1 Field tests conducted on Zian Co. Ltd. Headquarters at Boryeong, Chungnam, South Korea (a) layout of WAB stabilized soil columns at testing site; and (b) picture of actual installation of soil columns with WAB

Soil mixing was carried out by the wet method. Simultaneously, the WAB was mixed with water (see Fig.1; for design mix dosage rates and “volume-based” water-binder W/B ratio) forming a slurry before it was added into soil. Then, the soil-WAB slurry was injected during downward penetration through a pressurize pipe attached on the rotating mechanical blades. After 28 days 4 columns were cored (up to 5m depths) to investigate if the desired strength is reach. Then, cylindrical specimens with approximately 100mm by 50mm (L/D ratio of 2:1) were trimmed and the UCT were tested.

3 COMPARATIVE ANALYSIS

The lab specimens prepared at OMC to provide marginal references in evaluating the strength gain at lower free water contents and the effects of compaction on WAB reinforced soil-cement mixtures. Fig. 2 depicts the strength of WAB mixed (lab specimens), wherein q_u ascertains the increase in strength positively correlates with the increase in binder contents and curing days. The higher the dosage rate, the higher the strength.

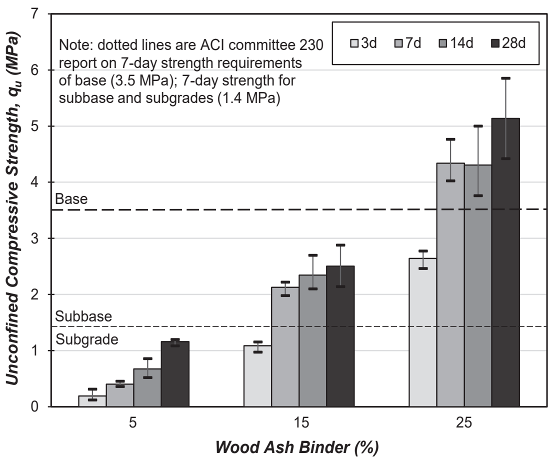

Fig. 2 Unconfined compressive strength of 5%, 15% and 25% WAB stabilized weathered granite soils (laboratory specimens)

Interestingly, active cementation was observed as early as 3 days when using low WAB contents. This significant cementation might suggest that mixing 20% cement and 30% GGBS can activate the pozzolanic activity of WA resulting to accelerated cementation. The unconfined compressive strength of 15% WAB and 25% WAB mix increase 2.30 and 1.94 times from 3 days to 28 days, respectively. On top of that, with the addition of 15% WAB and 25% WAB, the 28-day q_u increases 2.16 and 4.43 times compared to 5% WAB samples. On the other hand, Fig. 3 depicts the comparative results of q_u between laboratory and field specimens. The results of the q_u of field specimens with 17.2%, 23.7%, and 27.1% WAB mix were comparable. It is noteworthy that surficial voids were observed for the 23.7% and 27.1% WAB reinforced specimen. This might suggest the low measurements on UCT testing. On top of that, the 42.2% WAB dosage rate specimens show the highest q_u measurements compared with other mixtures.

The strength developments of cement-base materials are highly dependent on the amount of free water to cement (Abrams, 1918). Also, to achieve complete hydration, minimum free water (W/B ratio) of 0.25 is recommended (Murdock et al. 1991). Based on the experienced strength change of the lab specimens, additional free water was provided for the field tests to achieve workability (without compaction) applying regular construction procedure for soil-cement column. As a result, the comparative analysis of q_u between laboratory and field specimens is presented in Fig. 3.

Field tests show that q_u increases with the increase of the WAB dosage rate. In particular, the results of the 28-day cured 17.2% WAB specimen cored from the field tests range 2.6 to 3.0 MPa, and interestingly presenting a similar strength gain with the 15% WAB lab specimens. On the other hand, the q_u of 27.1% WAB core samples is lower than that of 23.7% WAB core samples. This might be attributed to the loose soil-WAB packing due to more free water in the 27.1% WAB specimens, indicating that the packing density of host soil's skeleton take critical role on the resulting strength of the mixture. On top of that, the 42.3% WAB specimen cored from the field tests present the highest strength gain (up to 7.2 MPa) with an average q_u of 5.1 MPa, and almost similar with 25% WAB treated lab specimens at 28 curing days.

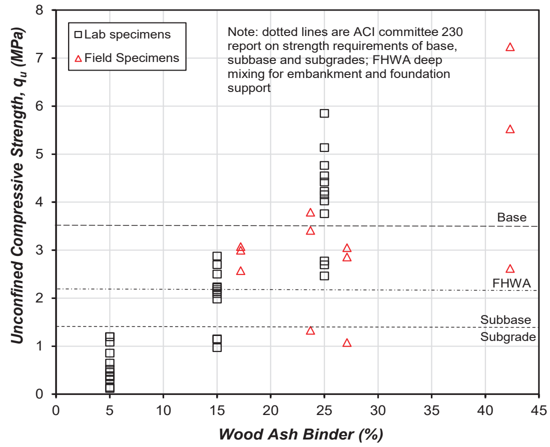

Fig. 3 Comparison of q_u of laboratory (3 to 28 days of curing) and field samples (28-day cured)

The notable differences in q_u for lab and field specimens are affected by the compaction efforts, relatively lower water contents (i.e. OMC), curing conditions, mixing and sampling tools. On the other hand, the dispersion in q_u measurements (for the field mixtures) might be attributed to (1) the high water contents of field tests (natural water contents with specified W/B ratio) which affects the packing matrix of soil and binder particles (2) disturbance effect during core sampling, and (3) the heterogeneity of the initial soil matrix due to the presence of unmixed soil-cement particles. Nonetheless, the findings of this study confirm the wide range of WAB applications (through laboratory and field tests), its developing mechanism, and its strength gained under different testing conditions.

Recycling of biomass ash has gained popularity in developing an alternative soil binder for ground improvement applications. Wherein the use biomass ash binder shows enhanced soil mechanical property, since it promotes equivalent pozzolanic activity between soil particles during aging (Ayininuola and Oyedemi, 2013; Roshni et al., 2015; Butt et al., 2016; Šķēls et al., 2016). Also, the use of combined GGBS blended with cement and lime products have shown significant effects on the geotechnical properties of soils such as permeability, compressive strength, settlement, shear strength and durability (Yi et al., 2014; Yu et al., 2016; He et al., 2019). For these reasons, the newly develop WAB also confirms the potential binding capacity with soil particles. It is noteworthy that the significant strength gain is also related with the change in soil microstructures. Further investigation on the morphology and microstructures of WS-WAB soils are required.

4 CONCLUSIONS

This study aims to develop a recycling technology for wood pellet fly ash as an alternative binder for soil structures by developing a new eco binder WAB (at wide range of dosage rate 5% to 42.3%). The findings of this study shows significant developments in the mechanical properties and microstructures of weathered granite soils for both laboratory and field tests. Also, the strength gain provided by 25% WAB (and greater for both lab and field coring samples) helps to qualify both ACI-230 7-day "base aggregates" strength requirements on pavement structures, and FHWA strength requirements for soil-cement structures. On top of that, the results of lab specimens present comparable trends with those of the field specimens. This study presents the potential performance of the newly developed wood ash binder as an eco-friendly binder for bioengineered soil-column structures.

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REFERENCES

AASHTO (1986). Guide for Design of Pavement Structures,

AASHTO (1986). Guide for Design of Pavement Structures, Washington, D.C.

Abrams, D.A. (1918) Design of Concrete Mixtures, Bulletin No. 1, Structural Materials Research Laboratory, Lewis Institute, Chicago.

ACI, 230.1R-09 Report on Soil Cement, 2009.

ASTM D1557-12e1 (2012) Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000ft-lbf/ft3(2,700 kN-m/m3)), D 1557, section 4, Vol. 04.08, Soil and Rock (I), ASTM, West Conshohocken, Pennsylvania, USA.

ASTM D2166 (2016) Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, D 2166, section 4, Vol. 04.08, Soil and Rock (I), ASTM, West Conshohocken, Pennsylvania, USA

Ayininuola, G.M., and Oyedemi, O.P. (2013). Impact of hardwood and softwood ashes on soil geotechnical properties. Transnational Journal of Science and Technology, 3(10), 1-7.

Butt, W.A., Gupta, K., and Jha, J.N. (2016). Strength behavior of clayey soil stabilized with saw dust ash. International Journal of Geo-Engineering, 7(1), 18.

Fletcher, K. (2015). Pellet trade between South Korea and Canada essentially came to a standstill this year, but recent coordination between the two may bring back opportunities. Available at: http://biomassmagazine.com/articles/12543/situation-south-korea (Accessed: February 10, 2022)

He, J., Wang, X.Q., Su, Y., Li, Z.X., and Shi, X.K. (2019). Shear strength of stabilized clay treated with soda residue and ground granulated blast furnace slag. Journal of Materials in Civil Engineering, 31(3), 06018029.

Kim, J.M. et al., (2021). Development of Non-Cement based Soil Stabilizer using Wood Pellet Fly Ash. Research report, Korea South-East Power Co. (KOEN), Korea (in Korean)

Ministry of Trade, Industry and Energy in Korea (MOTIE) (2017) "Renewable Energy 3020 Implementation Plan" (in Korean)

Ministry of Trade, Industry and Energy in Korea (MOTIE) (2017) "The 8th Basic Plan for Long-Term Electricity Supply and Demand" (in Korean). Vol. 2017-611, 2017

Murdock L.J., Brook K.M., and Dewar J.D. (1991) Concrete materials and practice. Edward Arnold, London, p 470

Proskurina, S., Junginger, M., Heinimö, J., Tekinel, B. and Vakkilainen, E. (2019), Global biomass trade for energy—Part 2: Production and trade streams of wood pellets, liquid biofuels, charcoal, industrial roundwood and emerging energy biomass. Biofuels, Bioprod. Bioref., 13: 371-387.

Roshni, R., Krishnan, K.D., and Ravichandran, P.T. (2015). Experimental study on strength behaviour of expansive soil treated with phosphogypsum and wood ash. Int. J. Sci. Res, 4(10), 161-164.

Šķēls, P., Bondars, K., Plonis, R., Haritonovs, V., and Paeglītis, A. (2016, September). Usage of wood fly ash in stabilization of unbound pavement layers and soils. In Proceedings of 13th Baltic Sea Geotechnical Conference, Vilnius (pp. 122-125).

Wood Resources International, South Korea, Japan wood pellet imports near records in late 2016. Biomass. [Online]. (2017). http://www.biomassmagazine.com/articles/14481/south-korea-japan-wood-pellet-imports-near-records-in-late-2016 [July 7, 2017]

Yi, Y., Liska, M., & Al-Tabbaa, A. (2014). Properties of two model soils stabilized with different blends and contents of GGBS, MgO, lime, and PC. Journal of Materials in Civil Engineering, 26(2), 267-274.

Yu, B.W., Du, Y.J., Jin, F., & Liu, C.Y. (2016). Multiscale study of sodium sulfate soaking durability of low plastic clay stabilized by reactive magnesia-activated ground granulated blast-furnace slag. Journal of Materials in Civil Engineering, 28(6), 04016016.