Geomechanics and Engineering, *Vol. 23, No. 1 (2020) 31-38*
DOI: https://doi.org/10.12989/gae.2020.23.1.031

Experimental study on the strength behavior of cement-stabilized sand with recovered carbon black

Kean Thai Chhun[1a], Hyunwook Choo[2b], Panyabot Kaothon[1c] and Chan-Young Yune*[1]

[1]*Department of Civil Engineering, Gangneung-Wonju National University, Jukheon-gil 7, Gangneung-si, Gangwon-do, 25457, Republic of Korea*
[2]*Department of Civil Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, 17104, Republic of Korea*

(Received June 15, 2020, Revised August 19, 2020, Accepted September 3, 2020)

Abstract. Soil-cement stabilization is a type of ground improvement method which has been used to improve the engineering properties of soil. The unconfined compression test is the commonly used method to evaluate the quality of the stabilized soil due to its simplicity, reliability, rapidity and cost-effectiveness. The main objective of this study was to evaluate the effect of recovered carbon black (rCB) on the strength characteristic of cement-stabilized sand. Various rCB contents and water to cement ratios (w/c) were examined. The unconfined compression test on stabilized sand with different curing times was also conducted for a reconstituted specimen. From the test result, it was found that the compressive strength of cement-stabilized sand increased with the increase of the rCB content up to 3% and the curing time and with the decrease of the w/c ratio, showing that the optimum rCB concentration of the tested stabilized sand was around 3%. In addition, a prediction equation was suggested in this study for cement-stabilized sand with rCB as a function of the w/c ratio and rCB concentration at 14 and 28 days of curing.

Keywords: cement stabilization; recovered carbon black; microfine cement; compressive strength; unconfined compression test

1. Introduction

Cement stabilization is a type of ground improvement method that has been widely used in construction work such as embankments (Mousavi 2016), tunnels (Tyagi *et al.* 2018), foundation (Shalabi *et al.* 2019), excavation (Fan *et al.* 2018), airport runways (Bocci *et al.* 2013), dams (Jackson 2013), and pavement (Guthrie 2007). Moreover, soil-cement stabilization has been commonly used, which is challenging due to the removal and then replacement of weak soils, because of its cost-effectiveness, environmental friendliness, and high durability. This method uses cement as a strengthening material to improve the strength and durability of the soil. Many laboratory studies have investigated numerous factors such as density, moisture content, cement concentration, curing condition, and fine particle content that effect the strength characteristics of soil-cement stabilization (Al-Aghbari *et al.* 2009, Stracke *et al.* 2012, Shooshpasha and Shirvani 2015, Moon *et al.* 2020, Kalantari 2010).

While the engineering properties of soil-cement stabilization have been investigated worldwide, some researchers have studied the combined effect of cement with additive materials such as fly as (Nath *et al.* 2017), lime (Jauberthie *et al.* 2010), rice husk ash (Balapour *et al.* 2017), slag (Mahedi *et al.* 2017), carbonate (Huang and Airey 1998), polymer (Ateş 2013), zeolite (Salamatpoor *et al.* 2018), and silica fume (Kalantari *et al.* 2010) on the mechanical and physical properties of the stabilized soil. From these studies, cement stabilization with an additive material offers important benefits improving the mechanical properties and the soil stiffness. Using recovered Carbon Black (*rCB*) which is a recycled material produced by waste tires, this study investigated the combined effect of cement and *rCB* on the engineering properties of cemented soil which has not been investigated much. Dehghanpour *et al.* 2019 investigated the effect of recycled nano carbon black on the mechanical and electrical properties of concrete. That study reported that the major effect of the recycled nano carbon black was a decrease in electrical resistivity and an enhancement of the compressive and flexural strength. Additionally, a comparative study was done by Tugume *et al.* 2019 on soils stabilized with a carbon black and crushed rock aggregates for a pavement base layer.

Thus, the main objective of this study was to evaluate the effect of *rCB* on the strength characteristics of the cement stabilized sand. The unconfined compression test on the stabilized soil containing different amounts of *rCB* was conducted and also the effect of the *w/c* ratio and curing

*Corresponding author, Professor
E-mail: yune@gwnu.ac.kr
[a]Ph.D. Candidate
E-mail: kt_chhun@yahoo.com
[b]Assistant Professor
E-mail: choohw@khu.ac.kr
[c]Graduate Student
E-mail: panyabotkaothon@gmail.com

ISSN: 2005-307X (Print), 2092-6219 (Online)

time on the stabilized soil was examined. The optimum *rCB* content in stabilized soil is also suggested in this study. Thereafter, the suggestion of a prediction equation to evaluate the compressive strength of cement stabilized sand with different amounts of *rCB* is introduced.

2. Materials and methods

2.1 Material used

In this study, Microfine Cement (*MC*) was used as the cementitious material. Based on the basic property test of the *MC*, the specific gravity was 2.96, and the specific surface was 6,800 cm^2/g. Additionally, the *MC* had a D_{95} of 20 μm (95% of the particles are finer than 20 μm). The chemical properties and the grain-size distribution of the *MC* are also presented in Table 1 and Fig. 1. The recovered carbon black with the average particle diameter of the *rCB* was 25.27 μm. The variation of the differential volume and particle diameter of the *rCB* is shown in Fig. 2. A commercial polycarboxylate (*AP-50*) was used as a superplasticizer to increase the dispersion of the *rCB* and *MC* particles and to improve the workability of the mixture. Additionally, the properties of the *AP-50* are shown in Table 2.

Fig. 1 shows the results of the grain-size distribution of the sand. The maximum ($\gamma_{d,max}$) and minimum ($\gamma_{d,min}$) dry unit weights are 16.56 and 13.57 kN/m^3, respectively (ASTM D 4253-14 2014; ASTM D 4254-14 2014). Based on the Unified Soil Classification system (*USCS*) (ASTM D2487-11 2011), the sand was classified as poorly graded sand (*SP*). The specific gravity of the sand was 2.67 according to ASTM D 854-02, 2002.

2.2 Sample preparation and test program

Four main groups of specimens according to the *w/c* ratio (0.5, 0.75, 1, and 1.25) were prepared with a different amount of *rCB* (0, 1, 3, 5, and 7% of the *MC* weight) to evaluate the effect of the *w/c* ratio and *rCB* on the compressive strength of cement-stabilized sand as shown in, Table 3. An amount of 1% *AP-50* by the weight of the *MC* was also added to improve the workability and consistency of the mixture. Fig. 3 shows the mixing procedure used here to prepare the mixture containing the *rCB*. To prepare the

Table 1 Chemical composition of the *MC*

Chemical composition (% by weight)	SiO_2	Al_2O_3 + Fe_2O_3	CaO + MgO	Na_2O + K_2O	SO_3
MC	28.34	11.9	57.9	0.64	3.07

Table 2 Properties of the superplasticizer

Appearance	Solid Content (%)	pH value	Viscosity (cps)	Specific gravity	Dosage % (20% base)
Brown liquid	50 ± 1	4 ± 2	1,000 Max.	1.10 ± 0.04	0.06 ~ 2.0

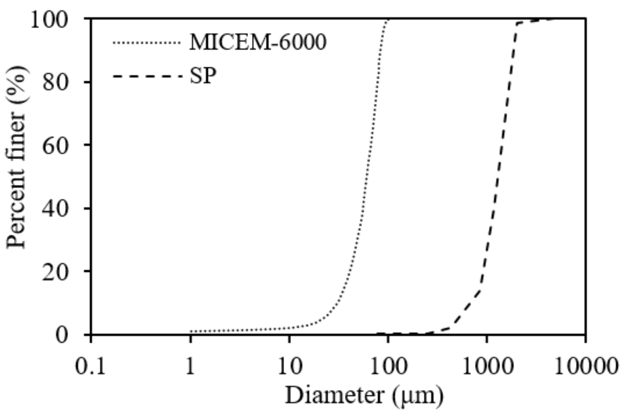

Fig. 1 Grain-size distribution of the sand and *MC*

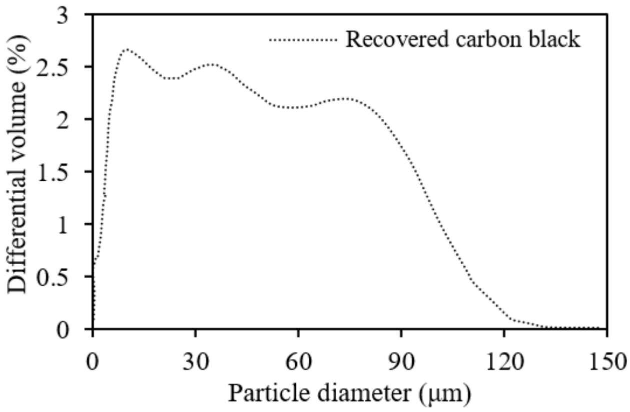

Fig. 2 Particle size analysis of the *rCB*

Table 3 Test conditions with different mixing ratios of the stabilized soil

Designation	*w/c* ratio	*AP*-50 (%)	*rCB* (%)	Curing time
0.5wc-0rCB	0.5	1	0	4, 7, 14, and 28 days
0.5wc-1rCB			1	
0.5wc-3rCB			3	
0.5wc-5rCB			5	
0.5wc-7rCB			7	
0.75wc-0rCB	0.75	1	0	
0.75wc-1rCB			1	
0.75wc-3rCB			3	
0.75wc-5rCB			5	
0.75wc-7rCB			7	
1wc-0rCB	1	1	0	
1wc-1rCB			1	
1wc-3rCB			3	
1wc-5rCB			5	
1wc-7rCB			7	
1.25wc-0rCB	1.25	1	0	
1.25wc-1rCB			1	
1.25wc-3rCB			3	
1.25wc-5rCB			5	
1.25wc-7rCB			7	

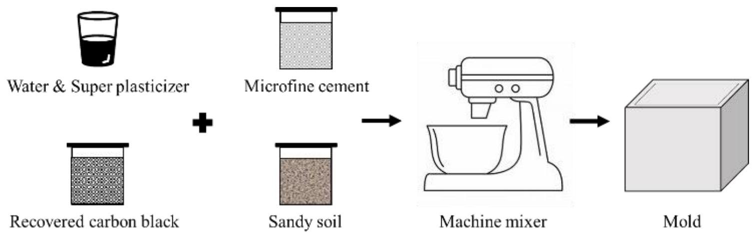

Fig. 3 Mixing procedure of the stabilized soil

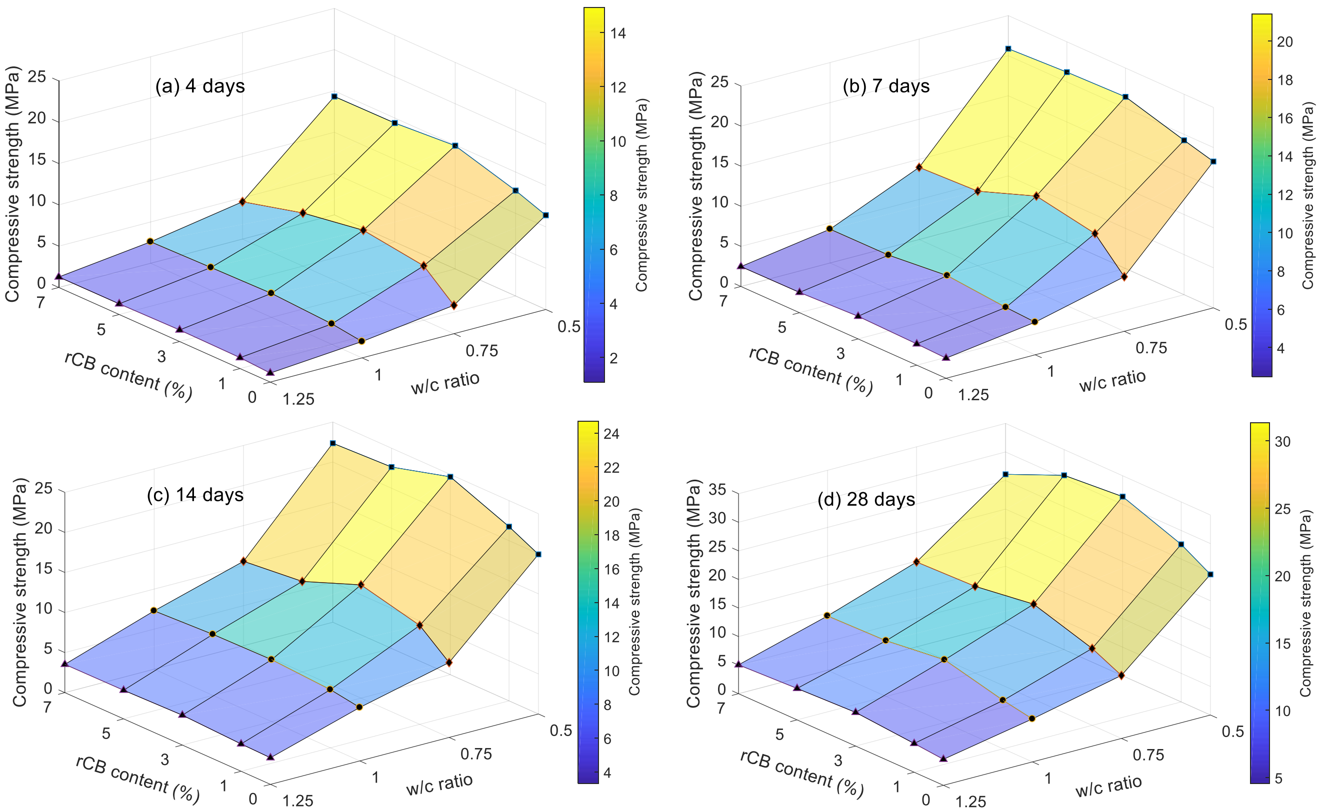

Fig. 4 Compressive strength of the stabilized soil: (a) 4 days, (b) 7 days, (c) 14 days and (e) 28 days of curing time

mixture, a predetermined amount of water and superplasticizer was first mixed at a speed of 100 rpm for 3 min. The *rCB* and *MC* were then poured into the mixture and stirred at a low speed for about 3 min. Finally, dry sand was added that corresponded to 60% of the relative densityand the mixture were mixed at a speed of 3 min at the speed of 300 rpm to ensure a well-mixed mixture. The mixed soil was poured into the metal mold (50 mm cube) for the unconfined compression test (ASTM D 4254-00 2002). Three cubic specimens were prepared for each mixture. After hardening for about 24 h, all samples were removed from the mold and transferred directly to the curing room at a temperature of 20 ± 2°C and a relative humidity higher than 95%.

2.3 Laboratory experiment

Three stabilized sand specimens (50 mm cube) were prepared for each test condition for the unconfined compression test according to ASTM C109/C109M-16a, 2016. A universal testing machine (*UTM*) with a capacity of 200 kN was used to compress the specimen at a rate of 1 mm per minute. The value of the compressive strength in each mixture was calculated by the average of the three samples.

3. Results and analysis

3.1 Effect of the w/c ratio, rCB content, and curing time

Many factors such as the *w/c* ratio, curing time, curing condition, and packing density influence the strength characteristics of cement-stabilized sand. In this study, the effect of the *w/c* ratio was examined on the compressive strength of the stabilized soil containing a *rCB* concentration ranging from 0 to 7%. Fig. 4 shows the three-dimensional plot of the test result of the compressive strength with different *w/c* ratios and *rCB* contents for each curing time. From this figure, the compressive strength of the stabilized soil containing *rCB* ranged from 0.10 to 31.35

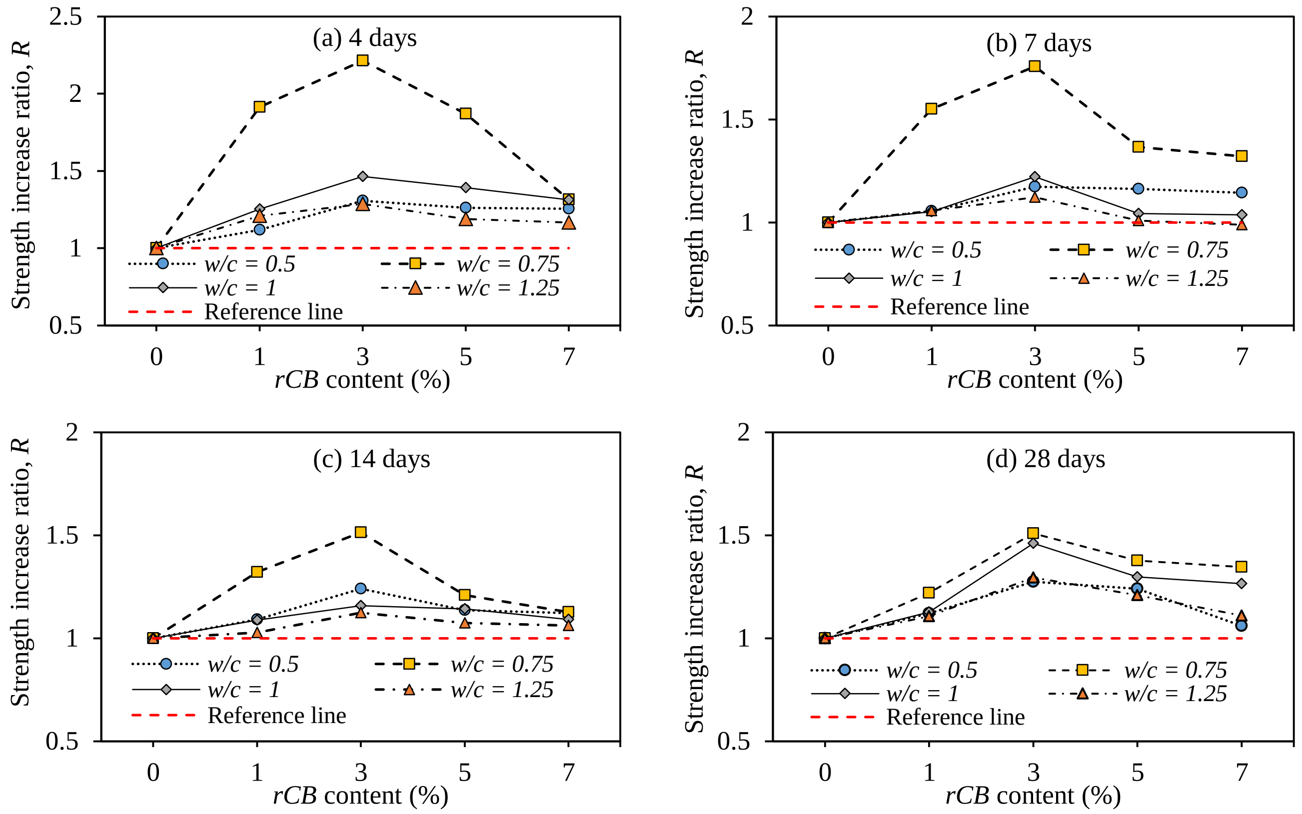

Fig. 5 Variation of the *rCB* on the compressive of stabilized soil: (a) 4 days, (b) 7 days, (c) 14 days and (d) 28 days of curing time

MPa. It can be clearly seen that the *rCB* content, *w/c* ratio and curing time have a significant influence on the compressive strength. Moreover, it was noted that the individual increase and the simultaneous increase of the *rCB* content, *w/c* ratio, and curing time, resulted in an increase of the compressive strength of the stabilized soil. The compressive strength of the specimens containing 0 to 7% of the *rCB* content exponentially increases with the decrease in the *w/c* ratio. Because of the decrease of the *w/c* ratio, the amount of water decreased in the mixture which tends to decrease the porosity in the stabilized sand. These present results are consistent with previous studies (Moon *et al.* 2020, Wei and Ku 2019, Ribeiro *et al.* 2016).

3.2 Effect of the rCB content on the compressive strength of the cement-stabilized sand

As mentioned earlier, the addition of *rCB* can enhances the compressive strength of cement-stabilized soil. As shown in Eq. (1), the increase ratio of the compressive strength of the cement-stabilized soil with the different amounts of *rCB* (*R*) was determined as the compressive strength of the stabilized soil containing *rCB* (q_{cs} with *rCB*) divided by the compressive strength of the stabilized soil without *rCB* (q_{cs} without *rCB*) for all curing times and *w/c* ratios (Salamatpoor *et al.* 2018, Park 2011). When the increase ratio of the compressive strength is equal to 1.0, the compressive strength with and without *rCB* is equal for each case of the *w/c* ratio. That means, even though the cement stabilized sand with a *w/c* ratio of 0.5 has the highest compressive strength, its increase ratio can have less strength compared to the other *w/c* ratios.

$$R = {q_{with\ rCB}} \Big/ {q_{without\ rCB}} \tag{1}$$

Similar to Fig. 4, Fig. 5 presents the result of the increase ratio of the compressive strength of stabilized soil containing different amounts of *rCB* at the curing times of 4, 7, 14, and 28 days, with the addition of a reference line. The results of the various *w/c* ratios of 0.5, 0.75, 1, and 1.25 are also plotted in Fig. 5. Based on the test results, the compressive strength increase ratio of the stabilized soil for all curing times and *w/c* ratios increased proportionally with the *rCB* concentration from 0 to 3%. This increase was due to the presence of the *rCB* which tended to decrease the pore space of the stabilized soil (Dehghanpour *et al.* 2019, Wen and Chung 2007, Ali *et al.* 2016) and also contributed to the hydration reaction of the stabilized soil by the formation of interparticle linkages becoming solid (Chen *et al.* 2011, Zhang *et al.* 2012). However, the compressive strength decreased after a *rCB* content greater than 3% due to the large amount of *rCB* which imparted their brittle characteristics to the stabilized soil. Thus, the effect of the *rCB* on the strength of the cement-stabilized soil becomes maximum at a *rCB* content of 3%. Moreover, it can be clearly seen that the effect of *rCB* for the soil-cement stabilized is quite similar to other additive material (fly as, lime, rice husk ash, slag, carbonate, polymer, zeolite, and silica fume) which provided the benefits enhancing the

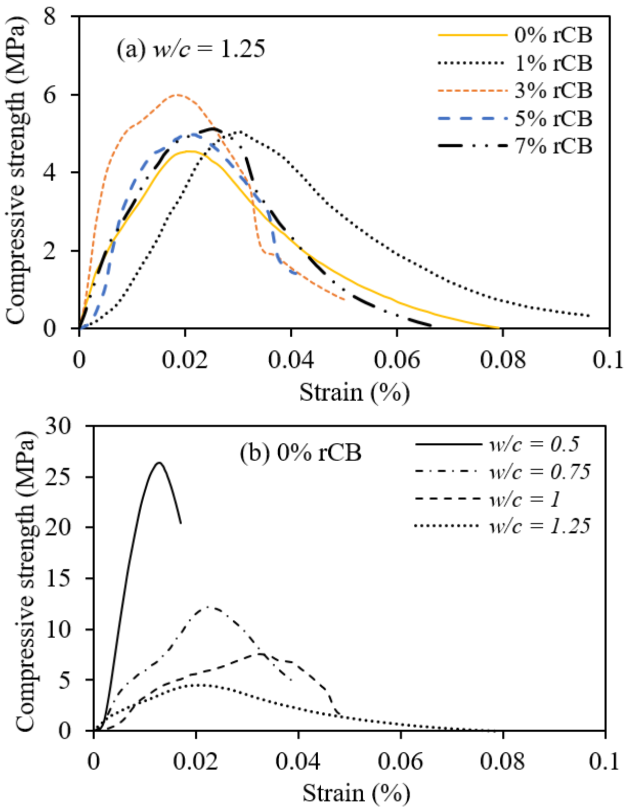

Fig. 6 Stress-strain curve at 28 days curing

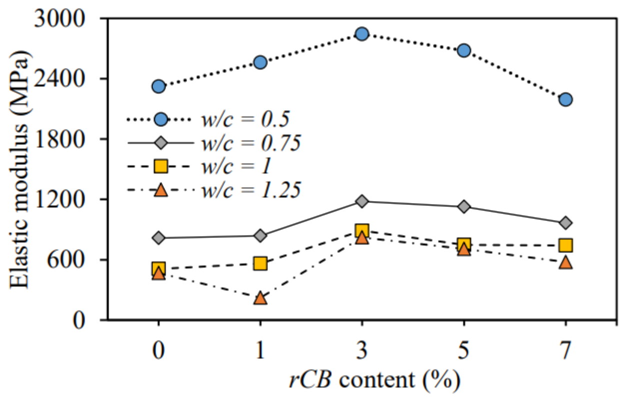

Fig. 7 Variation of elastic modulus with *rCB* content

mechanical properties and the soil stiffness. Additionally, the use of *rCB* which is a recycled material produced by waste tires, is not only offer these advantages but also can be an effective solution to reduce the pollution, waste, and disposal cost.

Noticeably, the graphs representing the variation in the strength increase ratio and the *rCB* content for all curing times show that the strength increase ratio appears to decrease with the curing days while the actual compressive strength increases with the curing days. It can be attributed to the fact that the matrices of the stabilized soil samples with *rCB* were highly filled because of the high specific surface area of the *rCB*, which decreases the pore space for a newly formed hydration product to settle in, contributing to the strength development. From this figure, even though the *w/c* ratio of 0.75 shows the highest strength increase ratio compared to the other *w/c* ratios, the *w/c* ratio of 0.5 provided the highest compressive strength.

3.3 Elastic modulus

The stress-strain curve of cement-stabilized sand with a various *rCB* concentration and *w/c* ratio was shown in Fig. 6. As mentioned above, three tests were conducted for each test condition on the cement-stabilized specimens, but only one stress-strain curve for each test was presented in Fig. 6 because the three curves showed almost the same trend. The elastic modulus (Young's modulus) was determined from the linear portion of the stress-strain curve from the compressive strength test. Fig. 7 presents the relationship between the elastic modulus at 28 days of curing with the *rCB* content for various *w/c* ratios from 0.5 to 1.25. From this, it was noted that the value of the elastic modulus of the stabilized soil increases with the addition of the *rCB* concentration from 0 to 7% at 28 days curing. Remarkably, the curves representing the elastic modulus of the stabilized soil with the different *rCB* concentrations showed that 3% *rCB* provided the optimum elastic modulus among all the *w/c* ratios which was similar to the result of the compressive strength. At the optimum *rCB* content, the elastic moduli were significantly increased by about 1.08, 1.44, and 3.46 times compared to the elastic moduli with 1.25 of the *w/c* ratio. As observed in Fig. 7, the elastic modulus of the stabilized soil linearly increased with the *rCB* content in the range of 0 to 3% *rCB* content. It can be noted that the *rCB* has an important role in enhancing the elastic modulus. However, when the *rCB* content increased from 3 to 7%, the elastic modulus of the stabilized soil decreased for all the *w/c* ratios which indicate the negative effect of an excessive amount of *rCB*.

4. Prediction of the compressive strength

The effect of the *w/c* ratio on the compressive strength of soil-cement stabilization can be estimated ideally by the following exponential Eq. (2) (Wei and Ku 2019). To consider the additional combined effect of the *w/c* ratio, *rCB*, and curing time on the compressive strength of stabilized soil, Eq. (2) can be expanded as the following Eq. (3). The reliability of the prediction equation can be evaluated by the coefficient of determination (R^2). The R^2 is the ratio of the variance in the measured compressive strength to the predicted compressive strength. The value of R^2 generally ranges from 0 to 1, and a value equal to 1 shows that the regression predictions perfectly match with the measured data.

$$q_{pcs} = q_0 \cdot \exp\left[-m\left(w/c\right)\right] \tag{2}$$

$$q_{pcs} = q_0 \cdot f(rCB) \cdot f(CT) \cdot \exp\left[-m\left(w/c\right)\right] \tag{3}$$

Here, q_{pcs} is the predicted strength of stabilized soil, q_0 is the fitting parameter, *rCB* is the recovered carbon black content, m is the fitting parameter, *CT* is the curing time,

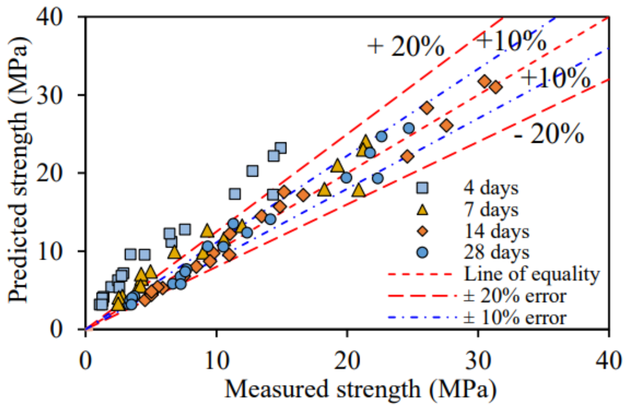

Fig. 8 Variation of the predicted and measured compressive strength of the stabilized soil

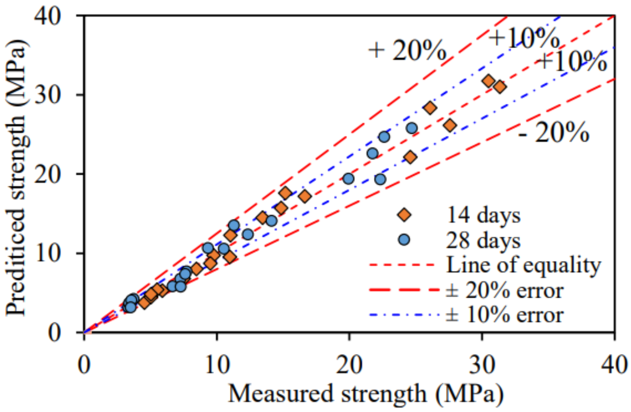

Fig. 9 Variation of the predicted and measured compressive strength of the stabilized soil

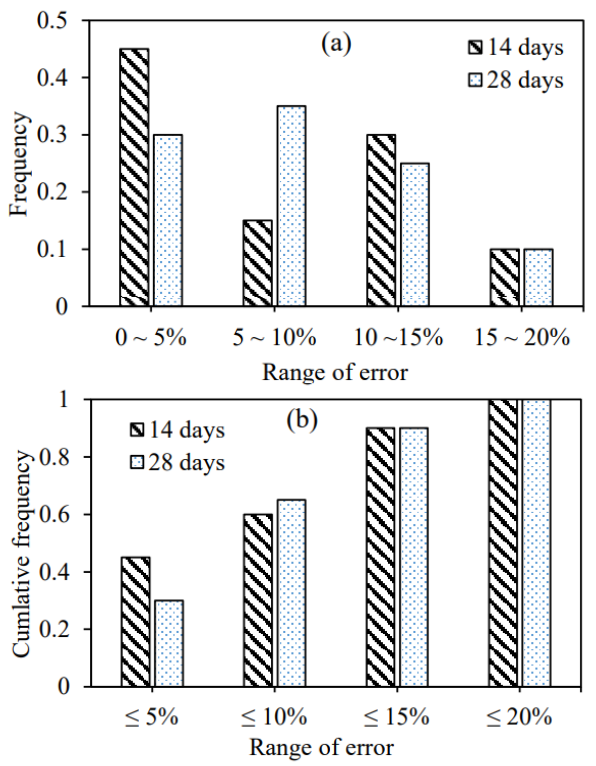

Fig. 10 Variation of the predicted and measured compressive strength of the stabilized soil at 14 and 28 days of curing

w/c is the water to cement ratio.

In this study, a total of 80 datasets were used to develop the prediction equation based on the master curve approach (McCabe *et al.* 2005). To predict the compressive strength of a stabilized sand with *rCB*, the developed prediction equations with various independent variables such as the *rCB* content, *w/c* ratio, and curing time are suggested by the following equation (4). Moreover, the accuracy and reliability of the prediction equation were evaluated by comparing the value of the predicted and measured compressive strength of the stabilized soil shown in Fig. 8. The red dashed line presents the line of equality between the predicted and measured strength. From this graph, R^2 was estimated as 0.8475. However, it was found that 53.75% of the predicted strength data have an error ($|q_{pcs}\text{-}q_{cs}|/q_{cs}\times100$) higher than 20% compared to the measured strength.

$$q_{PCS}=-1.776\cdot rCB^2+12.39\cdot rCB+64.83\cdot (0.067\ln(CT)+0.844)\cdot\exp(-2.411\cdot w/c) \quad (4)$$

As observed in Fig. 8, Eq. (4) overestimated the predicted strength, especially for 4 and 7 days of curing, showing that 80% of these data have an error higher than 20%. This is due to the nonlinear increase in the early age curing by the hydration process and also the contribution of the *rCB* concentration and *w/c* ratio. Therefore, the prediction equation provides the best value of R^2 in the case of 14 and 28 days curing. If the predicted and measured strength for 14 and 28 days curing was plotted as shown in Fig. 9, a good agreement can be observed with an R^2 of 0.976 and 0.982 for 14 and 28 days curing, respectively. In addition, all the predicted data, which were in the range of ± 20% of the measured strength, narrowed down its error limit to about ± 10% for a strength higher than 12 MPa. Even though, the unconfined compressive strength measured is not the real strength mobilized in the field, where significant confining pressure is applied, equation (4) can be used to estimate the compressive strength under the specified function of *rCB* content, *w/c* ratio, and curing time beforehand and to make a preliminary schedule of the construction.

Fig. 10(a) presents the frequency of the errors obtained from 14 and 18 days of curing at 5% intervals. It indicates that the number of frequency decreases with increasing percentage of error for both curing times; furthermore, the number of frequency at 28 days of curing is higher than that at 14 days except for 5 to 10% of error. The results show that all the predicted strengths are in the range of ± 20% (Fig. 10(b)).

5. Conclusions

In this present study, the experimental study on the strength behavior of cement-stabilized sand with *rCB* was investigated. The effect of the *rCB*, *w/c* ratio, and curing time on the compressive strength was then examined. Based on the test result, the following conclusion could be made:

• The *rCB* concentration, *w/c* ratio, and curing time were strongly influenced by the strength characteristic of the stabilized soil. The compressive strength increased with the increase in the *rCB* content and curing time and decreased with the increase in the *w/c* ratio.

• The results of this experiment found that the optimum ratio of the 3% *rCB* concentration in the stabilized soil should be used to obtain the maximum values of compressive strength and elastic modulus.

• The prediction equations were suggested for the high accuracy of cement-stabilized soil based on the function of the *w/c* ratio, and *rCB* content. This equation yields the correct predicted strength about 98% for an error less than 20% for the curing times of 14 and 28 days. Further study, which take more parametric (soil types and/or curing condition) and the field confirmation, will need to be investigated.

In summary, the stabilized soil-cement containing the waste material *rCB* was advantageous regarding the stability, durability, and cost-effectiveness compared to other cementation stabilizations. Moreover, this cemented soil used only a small amount of *rCB* which offers a better strength and can be used at various construction sites.

Acknowledgments

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 20SCIP-C151438-02/20SCIP-C151585-02). We gratefully acknowledge Mr. Cho Heung-Seok for his support of this project.

References

Al-Aghbari, M.Y., Mohamedzein, Y.E.A. and Taha, R. (2009), "Stabilisation of desert sands using cement and cement dust", *Proc. Inst. Civ. Eng. Ground Improv.*, **162**(3), 145-151. https://doi.org/10.1680/grim.2009.162.3.145.

Ali, A.D., Mohammad, H.S., Oğuzhan, Ö., Gürkan, Y., Arife, A., Mustafa, Ş. and Mohamed, L. (2016), "Electrical percolation threshold of cementitious composites possessing self-sensing functionality incorporating different carbon-based materials", *Smart Mater. Struct.*, **25**(10), 1-15. https://doi.org/10.1088/0964-1726/25/10/105005.

ASTM D 4253-14 (2014), Standard test method for maximum index density and unit weight of soils using a vibratory table, Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, Pennsylvania, U.S.A., 1-14.

ASTM D 4254-00 (2002), Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, Pennsylvania, U.S.A., 1-10.

ASTM D 4254-14 (2014), Standard test method for minimum index density and unit weight of soils and calculation of relative density, Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, Pennsylvania, U.S.A., 1-9.

ASTM D 854-02 (2002), Standard test method for specific gravity of soil solids by water pycnometer, Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, Pennsylvania, U.S.A., 1-7.

ASTM D2487-11 (2011), Standard practice for classification of soils for engineering purposes (Unified soil classification system), Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohocken, Pennsylvania, U.S.A., 1-12.

Ateş, A. (2013), "The effect of polymer-cement stabilization on the unconfined compressive strength of liquefiable soils", *Int. J. Poly. Sci.*, 1-8. http://doi.org/10.1155/2013/356214.

Balapour, M., Hajibandeh, E. and Ramezanianpour, A. (2018), "Engineering properties and durability of mortars containing new nano rice husk ash (RHA), high tech concrete: Where technology and engineering meet", *Proceedings of the 2017 Fib Symposium*, Maastricht, The Netherlands, June.

Bocci, M., Manganaro, A., Stramazzo, V. and Grilli, A. (2013), "Runway pavement reconstruction with full material recycling: The case of the airport of Treviso", *Adv. Mater. Res.*, **723**, 1044-1051. https://doi.org/10.4028/www.scientific.net/AMR.723.1044.

Chen, L., Du, Y.J., Liu, S.Y. and Jin, F. (2011), "Evaluation of cement hydration properties of cement-stabilized lead-contaminated soils using electrical resistivity measurement", *J. Hazard. Toxic Radio. Waste*, **15**(4), 312-320. https://doi.org/10.1061/(ASCE)HZ.1944-8376.0000073.

Dehghanpour, H., Yilmaz, K. and Ipek, M. (2019), "Evaluation of recycled nano carbon black and waste erosion wires in electrically conductive concretes", *Constr. Build. Mater.*, **221**(10), 109-121. https://doi.org/10.1016/j.conbuildmat.2019.06.025.

Fan, J., Wang, D. and Qian, D. (2018), "Soil-cement mixture properties and design considerations for reinforced excavation", *J. Rock Mech. Geotech. Eng.*, **10**(4), 791-797. https://doi.org/10.1016/j.jrmge.2018.03.004.

Guthrie, W.S., Brown, A.V. and Eggett, D.L. (2007), "Cement stabilization of aggregate base material Blended with reclaimed asphalt pavement" *Transport. Res. Rec.*, **2026**(1), 47-53. https://doi.org/10.3141/2026-06.

Huang, J.T. and Airey, D.W. (1998), "Properties of artificially cemented carbonate sand", *J. Geotech. Geoenviron. Eng.*, **124**(6), 492-499. https://doi.org/10.1061/(ASCE)1090-0241(1998)124:6(492).

Jackson, J.O. (1974), "The effect of leaching on soil-cement", *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, **11**(6), 215-219. https://doi.org/10.1016/0148-9062(74)90128-4.

Jauberthie, R., Rendell, F., Rangeard, D. and Molez, L. (2010), "Stabilization of estuarine silt with lime and/or cement", *Appl. Clay Sci.*, **50**(3), 395-400. https://doi.org/10.1016/j.clay.2010.09.004.

Kalantari, B. (2011), "Strength evaluation of air cured, cement treated peat with blast furnace slag", *Geomech. Eng.*, **3**(3), 207-218. https://doi.org/10.12989/gae.2011.3.3.207.

Kalantari, B., Prasad, A. and Huat, B.B.K. (2010), "Stabilising peat soil with cement and silica fume", *Proc. Inst. Civ. Eng. Geotech. Eng.*, **164**(1), 33-39. https://doi.org/10.1680/geng.900044.

Mahedi, M., Cetin, B. and White, D.J. (2018), "Performance evaluation of cement and slag stabilized expansive soils", *Transport. Res. Rec.*, **2672**(52), 164-173. https://doi.org/10.1177/0361198118757439.

McCabe, D.E., Merkle, J.G. and Wallin, K. (2005), An introduction to the development and use of the master curve method, ASTM International, West Conshohocken, Pennsylvania, U.S.A.

Moon, S., Vinoth, G., Subramanian, S., Kim, J. and Ku, T. (2020), "Effect of fine particles on strength and stiffness of cement treated sand", *Granul. Matter*, **22**(9), 1-13. https://doi.org/10.1007/s10035-019-0975-6.

Mousavi, S.E. (2016), “Stabilization of compacted clay with cement and/or lime containing peat ash”, *J. Road Mater. Pav. Des.*, **18**(6), 1304-1321, https://doi.org/10.1080/14680629.2016.1212729.

Nath, B.D., Molla, M.K.A. and Sarkar, G. (2017), “Study on strength behavior of organic soil stabilized with fly ash”, *Int. Schol. Res. Not.*, 1-6. https://doi.org/10.1155/2017/5786541.

Park, S.S. (2011), “Unconfined compressive strength and ductility of fiber-reinforced cemented sand”, *Constr. Build. Mater.*, **25**(2), 1134-1138. https://doi.org/10.1016/j.conbuildmat.2010.07.017.

Ribeiro, D., Néri, R. and Cardoso, R. (2016), “Influence of water content in the UCS of soil-cement mixtures for different cement dosages”, *Proc. Eng.*, **143**, 59-66. https://doi.org/10.1016/j.proeng.2016.06.008.

Salamatpoor, S., Jafarian, Y. and Hajiannia, A. (2018), “Physical and mechanical properties of sand stabilized by cement and natural zeolite”, *Eur. Phys. J. Plus*, **133**(205), 1-13. https://doi.org/10.1140/epjp/i2018-12016-0.

Shalabi, F.I., Mazher, J., Khan, K., Alsuliman, M., Almustafa, I., Mahmoud, W. and Alomran, N. (2019), “Cement-stabilized waste sand as sustainable construction materials for foundations and highway roads”, *Materials*, **12**(4), 600. https://doi.org/10.3390/ma12040600.

Shooshpasha, I. and Shirvani, R.A. (2015), “Effect of cement stabilization on geotechnical properties of sandy soils”, *Geomech. Eng.*, **8**(1), 17-31. https://doi.org/10.12989/gae.2015.8.1.017.

Stracke, F., Jung, J.G., Korf, E.P. and Consoli, N.C. (2012), “The influence of moisture content on tensile and compressive strength of artificially cemented sand”, *Soils Rocks*, **35**(3), 303-308.

Tugume, B., Owani, I., Jjuuko, S. and Kalumba, D. (2019), “Performance of lateritic soils stabilized with both crushed rock aggregates and carbon black as a pavement base layer”, *Proceedings of the 8th International Congress on Environmental Geotechnics*, Singapore, October.

Tyagi, A., Liu, Y., Pan, Y.T., Ridhwan, K.B.M. and Lee, F.H. (2018), “Stability of tunnels in cement-admixed soft soils with spatial variability”, *J. Geotech. Geoenviron. Eng.*, **144**(12), 06018012:1-7. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001988.

Wei, X. and Ku, T. (2019), “New design chart for geotechnical ground improvement: characterizing cement-stabilized sand”, *Acta Geotech.*, **15**(4), 999-1011. https://doi.org/10.1007/s11440-019-00838-2.

Wen, S. and Chung, D.D.L. (2007), “Partial replacement of carbon fiber by carbon black in multifunctional cement–matrix composites”, *Carbon*, **45**(3), 505-513. https://doi.org/10.1016/j.carbon.2006.10.024.

Zhang, D.W., Chen, L. and Liu, S.Y. (2012), “Key parameters controlling electrical resistivity and strength of cement treated soils”, *J. Central South Univ.*, **19**(10), 2991-2998. https://doi.org/10.1007/s11771-012-1368-8.

GC