Effect of Mineral Additives on the Strength Characteristics of a Laterite Soil

Tri Harianto and Widya Dwi Utami

Abstract The road access opening, frequently through several soil conditions, do not comply with the construction requirements. Thus, it needed materials that could protect the low bearing capacity of subgrade and strengthen the pavement layers from a load of the vehicle's wheel. This study aimed is to analyze the performance of the subbase layer, which consists of zeolite-stabilized laterite soil using water glass as an activator. The mechanical characteristics of the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) value were investigated in this study. The soil sample was prepared with a zeolite percentage of 4, 8, 12, 16, 20%, and combining with 2% of water glass. Prior to the test, the soil samples set to the maximum dry density (MDD) and optimum moisture content (OMC) condition. The result of the mechanical characteristics of the stabilized soil showed that the higher UCS and CBR value was observed compared to untreated soil. The mechanism of the improvement of stabilized soil is also discussed.

Keywords Soil strength · Zeolite · Water glass

1 Introduction

The laterite soil derived from a wide variety of rocks weathering under strongly oxidizing and leaching conditions and rich in iron oxide. Laterite soil generally found in the humid climate, and it forms in a tropical and subtropical region. The climate (temperature, precipitation, leaching, and capillary rise), topography (drainage), vegetation, parent rock (iron-rich rocks), and time of these primary factors are the factors in the laterite formation.

Lateritic soils are indigenous materials that are cheaper and abundantly available as construction materials. Previous works reported the treatment of reclaimed asphalt pavement (RAP) with coal fly ash, RAP with new aggregates, and lateritic soil with forage ash. The results show that the CBR of lateritic soil improved with up to 6%

T. Harianto (✉) · W. D. Utami
Hasanuddin University, Perintis Kemerdekaan, 90245 Makassar, Indonesia
e-mail: triharianto@unhas.ac.id

H. Hazarika et al. (eds.), *Advances in Sustainable Construction and Resource Management*, Lecture Notes in Civil Engineering 144,
https://doi.org/10.1007/978-981-16-0077-7_37

forage ash treatment [1]. Laboratory testing results also show that the stabilization of lateritic soil improved California bearing ratio (CBR) and resilient modulus (Mr) values significantly [2–4].

Recently, the utilization of fiber in cement-stabilized soil increased the strength of the treated soil significantly [5, 6]. The ductility significantly improves without changing the compressive strength by the existence of fiber in the cement–soil mixture. The existence of fiber in the cement–soil mixture can suppress the development of crack formation during the unconfined compressive strength (UCS) test [7]. Moreover, the utilization of cement has severe environmental impacts, as it involves using vast amounts of fossil fuels as well as being responsible for the emission of more than 5% of all the carbon dioxide released worldwide [8]. Therefore, an attempt to reduce using cement in soil stabilization is increasing.

The utilization of mineral additive has received attention for potential applications in the soil stabilization method. The application of local material content (i.e., zeolite and water glass) as an additive to the lateritic soil has not widely applied. Therefore, the potential application of zeolite and water glass as an additive to improve the strength of laterite soil was investigated in this study.

2 Materials and Methods

2.1 Materials

The lateritic soil used in this study was collected from a borrow pit as disturbed samples at Sangkaropi, Toraja, Indonesia. The lateritic soil was crushed using a hand hammer, from its lump state to smaller sample sizes able to pass through a 0.425-mm aperture sieve following ASTM C702-98 (2003). The natural moisture content of the lateritic soil was determined to be 32% and classified as a silt with high plasticity (MH).

The stabilization agent used in this study was zeolite with water glass (sodium silicate) as an activator. Zeolite is crystalline alumino-silicates consisting of three-dimensional frameworks of SiO_4 and AlO_4 linked through oxygen bridges. The zeolite was crushed state to smaller sample sizes able to pass through a 0.075-mm aperture sieve following ASTM C702-98 (2003).

2.2 Methods

The lateritic soil (LS) and zeolite water glass-stabilized laterite (ZW-LS) soil were tested to determine the index properties, particle-size distribution, soil classification, specific gravity, and compaction characteristics following procedures outlined in standard ASTM codes. The unconfined compression test (UCT) and the California bearing ratio (CBR) unsoaked tests were carried out in accordance with the procedure outlined in ASTM D2166 and D1883-07e2, respectively. Lateritic soil was stabilized with zeolite by concentrations of 4, 8, 12, 16, and 16% and 2, 4, and 6% of water glass solution. All the specimens were subjected to curing for 7, 14, and 28 days. Prior to the test, the soil specimens were set to the maximum dry density (MDD) and optimum moisture content (OMC) condition. An optimum proportion is determined during the preliminary mix design tests.

3 Results and Analysis

3.1 Laterite Soil Characteristics

The soil sample was air dried for one day prior to testing in order to simulate the fields' condition. This procedure conducted due to the different environment usually affected the index properties of the soil samples [9]. The physical and mechanical properties of soil sample are summarized in Table 1. The engineering properties of the soil sample were determined in accordance with American Society for Testing and Materials (ASTM, 1992).

Table 1 Properties of the lateritic soil

Designation	Value	Unit
A. Physical properties		
Specific gravity	2.68	
Nature water content	32	%
Soil classification		
a. USCS	MH	
b. AASTHO	A-5	
Atterberg limit		
a. Liquid limit (LL)	59	%
b. Plastic limit (PL)	49	%
c. Plasticity index	10	%
B. Mechanical properties		
Standard proctor test		
a. Optimum moisture content (OMC)	25	%
b. Maximum dry density (MDD)	14.8	KN/m^3
Unconfined compression test (UCT)		
Compressive strength	97.1	KN/m^2
California bearing ratio (CBR)		
Unsoaked	19.0	%

3.2 Unconfined Compressive Strength

The variation of UCS of ZW-stabilized LS with curing time for 0, 7, 14, and 28 days is shown in Fig. 1. Based on these results, there is a general increase in the UCS values with increasing zeolite and water glass content. Generally, the increase of UCS value was found to 3–25 times of magnitude (300–2500 N/m^2) compared to untreated soil (97.1 kN/m^2). The highest increase of UCS value was found for 20% zeolite and 6% of water glass. This behavior tends to be similar to other zeolite and water glass content. In a mixture of 20% zeolite and 6% water glass (28 days curing time), an increase of soil strength is almost 25 times of magnitude compared to untreated LS. Increasing the strength of ZW-stabilized LS is strongly influenced by the content of minerals present in the zeolite and water glass.

The variation of the UCS value of zeolite-stabilized LS with various water glass content is shown in Fig. 2. All the UCS tests are conducted with 0, 7, 14, and 28 days. Based on these results, there is a general tendency of the increase in the UCS values with increasing zeolite and water glass content. Generally, the significant improvement of UCS value is for up to 7 days. The highest increase of UCS value was found for 6% of water glass. This behavior tends to be similar to other zeolite and water glass content. In a mixture of 20% zeolite and 6% water glass (28 days curing time), an increase of soil strength is almost 25 times of magnitude compared to untreated LS. The improvement magnitude of UCS in all various mixing for 7 days

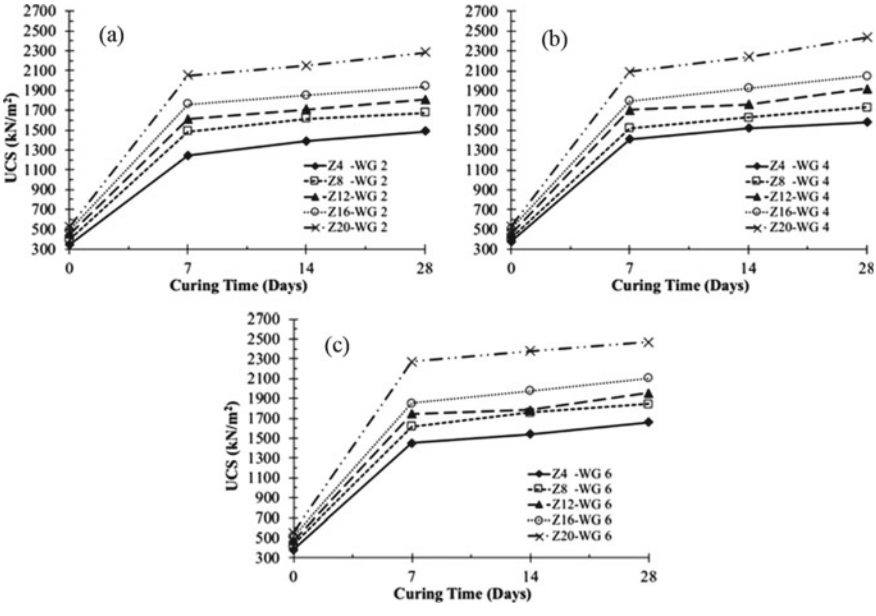

Fig. 1 Variation of UCS value with various curing time: **a** 2% of water glass, **b** 4% of water glass, and **c** 6% of water glass

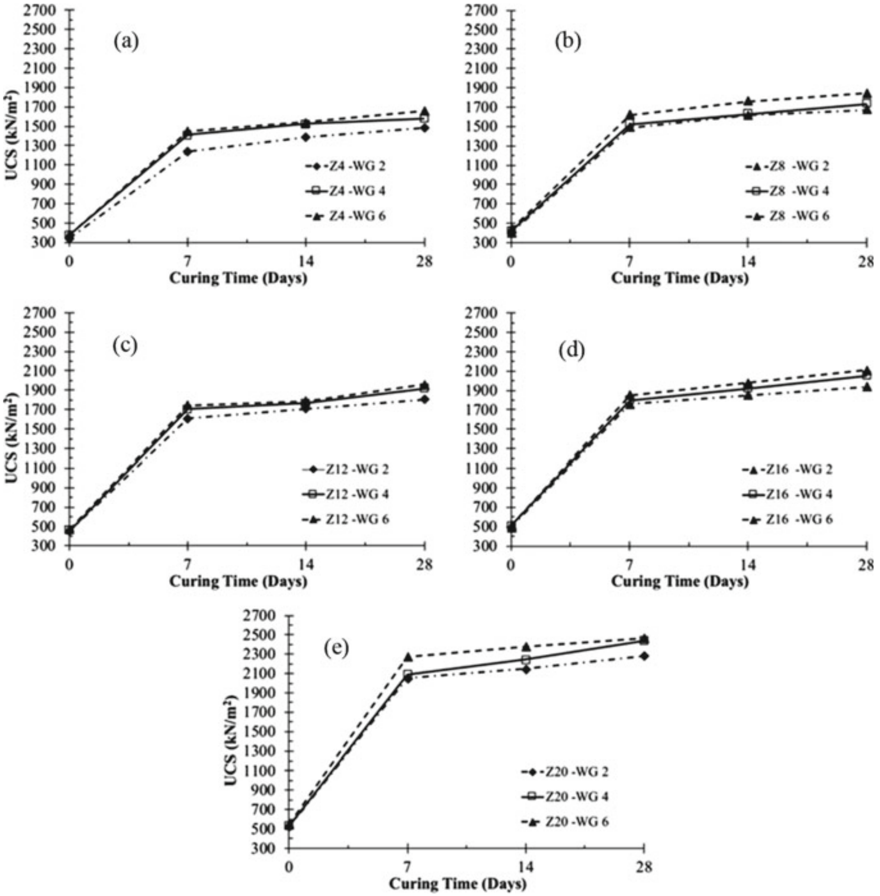

Fig. 2 Variation of UCS value with various zeolite content and curing time: **a** 4% of zeolite, **b** 8% of zeolite, **c** 12% of zeolite, **d** 16% of zeolite, and **e** 20% of zeolite

curing time as a primary cementing process is shown in Fig. 3. It can be seen that for the higher water glass content, the increase of the magnitude of UCS improvement is higher due to the higher amount of zeolite–water glass hydration products. Therefore, the water glass has a significant effect on the zeolite-stabilized LS improvement.

The increase in the UCS mainly attributed to the reactions between soil and additive materials (zeolite and water glass), including pozzolanic reaction. This products bind the ZW and LS particles together into a strong matrix [10]. The high silica and alumina in the zeolite reacted with mineral in Lateritic soil. This is because fine-grained soil particle composition (SiO_2, Al_2O_3) also participate in cementation reaction [11, 12].

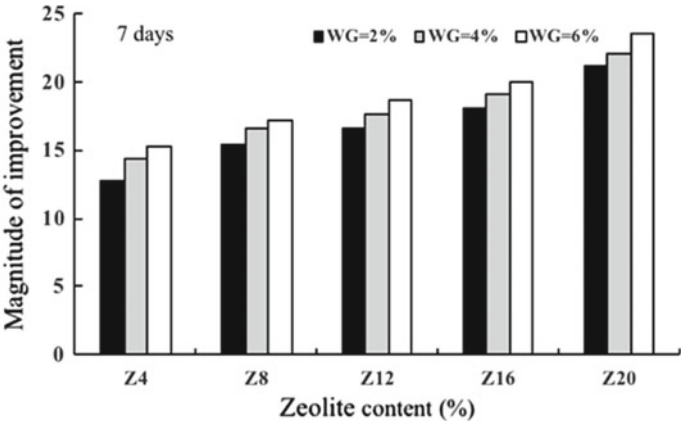

Fig. 3 Magnitude of UCS improvement of zeolite-stabilized LS with water glass activator

3.3 *California Bearing Ratio*

The variation of CBR (unsoaked) of ZW-stabilized LS mixes with various curing time is shown in Figs. 4 and 5. The CBR value of the ZW-stabilized LS increased with

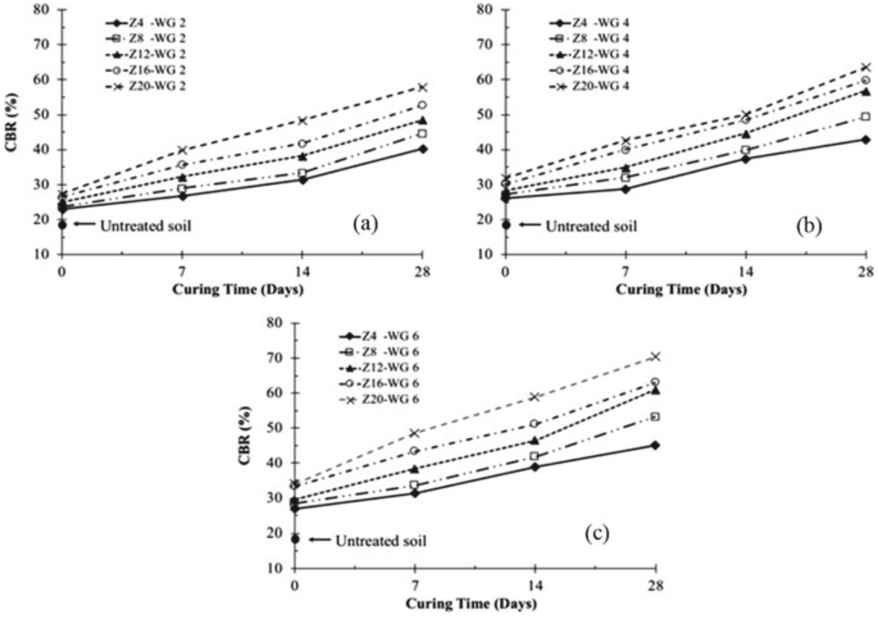

Fig. 4 Variation of CBR value with various curing time: **a** 2% of water glass, **b** 4% of water glass, and **c** 6% of water glass

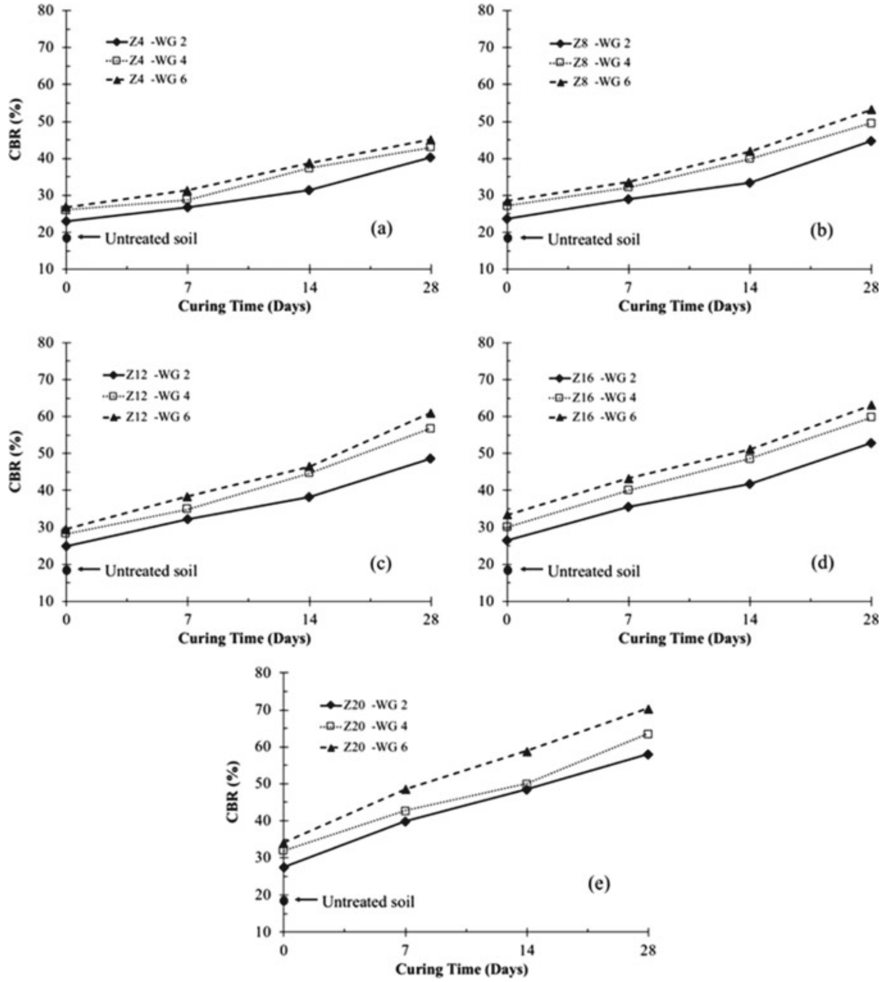

Fig. 5 Variation of CBR value with various curing time: **a** 4% of zeolites, **b** 8% of zeolite, **c** 12% of zeolite, **d** 16% of zeolite, and **e** 20% of zeolite

increased curing time. Increasing zeolite content also increases the CBR value, and the highest CBR value was found for 28 days. The CBR value of ZW-stabilized LS mixes for 28 days curing time shows that the CBR value increased three times greater of 2% water glass and almost four times of 6% water glass compared to the untreated LS. These values met the requirement of Indonesian National Standard (SNI-03-3438-1994) for subgrade and subbase layer of pavement foundation. The Indonesian general specification recommended that a minimum CBR value of subgrade and subbase are 6 and 20%, respectively.

The reason for this improvement is due to the pozzolanic reactions of zeolite with laterite soil. This results in the agglomeration of soil particles and causes an increase in strength gain. Overall, it is observed that the addition of water glass on the zeolite-stabilized LS leads to an improvement of CBR value. This increase reflected an improvement of bearing capacity of the zeolite-stabilized LS mixed with water glass. The bearing capacity improvement is a result of the stiffening of the soil by effect of the cement hydration [12]. Moreover, the increasing of CBR value of the cement-treated soil is in good agreement with the previous study by [13] and [14].

4 Conclusions

The present study was conducted to investigate and evaluate the effectiveness of water glass as an activator mixed with zeolite-stabilized laterite soil. The zeolite and water glass were mixed with the laterite soil and compacted at various zeolite and water glass content. Lateritic soils are indigenous materials that are cheaper and abundantly available as construction materials. The UCS value increased significantly with the addition of **zeolite** and water glass compared to the untreated soil. The high silica and alumina in the zeolite reacted with mineral in lateritic soil. This is because fine-grained soil particle composition (SiO_2, Al_2O_3) also participates in cementation reaction. The CBR value of the ZW-stabilized LS increased with increased curing time. Increasing zeolite and water glass content also increase the CBR value, and the highest UCS and CBR value was found for 28 days. These values met the requirement of Indonesian National Standard (SNI-03-3438-1994) for subgrade and subbase layer of pavement foundation. The Indonesian general specification recommended that a minimum CBR value of subgrade and subbase are 6 and 20%, respectively.

References

1. Olugbenga, O.A., Nurudeen, T.B., Adewale, A.C.: Effects of forage ash as stabilizing agent in lateritic soil for road. Innov. Sci. Eng. **1**, 1–8 (2011)
2. Edil, T.B., Benson, C.H.: Sustainable Construction Case History: Fly Ash Stabilization of Road-Surfaced Gravel. World of Coal Ash, Covington, KY (2007)
3. Hatipoglu, B., Edil, T.B., Benson, C.H.: Evaluation of base prepared from Rd. surface gravel stabilized with fly ash. In: Proceedings of Geo-Congress 2008: Geotechnics of Waste Management and Remediation, ASTM, West Conshohocken, PA, pp. 288–295 (2008)
4. Osinubi, K.J.: Influence of compaction delay on the properties of cement stabilized lateritic soil. J. Eng. Res. **6**(1), 13–25 (1998)
5. Harianto, T., Du, Y., Hayashi, S., Suetsugu, D., Nanri, Y.: Geotechnical properties of soil-fibre mixture as a landfill cover barrier material. Geotech. Eng. J. Southeast Asian Geo Soc. **39**(3), 137–143 (2008)
6. Tang, C., Shi, B., Gao, W., Chen, F., Cai, Y.: Strength and mechanical behaviour of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext. Geomemb. **25**, 194–202 (2007)
7. Liu, C., Starcher, R.D.: Effects of curing conditions on unconfined compressive strength of cement and cement-fiber-improved soft soil. J. Mater. Civ. Eng. **25**(8), 1134–1141 (2013). https://doi.org/10.1061/(ASCE)MT.1943-5533.0000575

8. Provis, J., Deventer, J.V.: Alkali Activated Materials: State of the Art Report. RILEM TC 224-AAM, Springer, Netherlands (2014)
9. Moh. Z.C., Mazher, M.F.: Effects of method of preparation on index properties of lateritic soils. In: Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, Mexico, vol. 1, pp. 23–25 (1969)
10. Li, L., Benson, C.H., Edil, T.B.: Sustainable construction case history: fly ash stabilization of recycled asphalt pavement materials. J. Geotech and Geo. Eng. **26**(2), 177–187 (2008)
11. Mariri, M., Ziaie Moayed, R., Kordnaeji, A. Stress-strain behavior of loess soil stabilized with cement, zeolite and recycled fiber. J. Mater. Civil Eng. **31**(12), 04019291-1–04019291-10 (2019)
12. Harianto, T., Sitepu, F., Jasruddin: Strength improvement of cement stabilized soil by binder mineral additive. Lowland Technol. Int. J. **21**(2), 90–97 (2019)
13. Osula, D.O.A.: Evaluation of admixture stabilization for problem laterire. J. Transp. Eng. **115**(6), 674–687 (1989)
14. Mengue, E., Mroueh, H., Lancelot, L., Eko, R.M.: Mechanical improvement of a fine-grained lateritic soil treated with cement or use in road construction. J. Mater. Civ. Eng. **29**(11), 040172061–040172122 (2017). https://doi.org/10.1061/(ASCE)MT.1943-5533.0002059