Strength Characteristics of Soda Waste Treated with Fly Ash and Lime

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ABSTRACT: Soda waste is a kind of industrial waste when traditional technology of soda production is adopted. The soda waste cannot be directly used as engineering soil as its low strength. However, it can be used after be mixed with other materials. In this paper, chemical materials such as fly ash and lime are used to be mixed with soda waste. The strength characteristics of soda mixtures with different ratio are studied in detail. Compaction test and unconfined compressive test are conducted respectively to assess the feasibility of these two materials. Based on test results, the mechanical properties of soda mixtures with different ratios of fly ash and lime are discussed. It is indicated that the microstructure of soda waste is similar with soil and the particle size distribution is well to mix with other materials to be used as engineering soil. The optimal ratio of soda waste and fly ash is 7:3 while the ratio is 7 % for soda waste and lime. Using the optimal ratio, the unconfined compression strength of fly ash treated soda and lime treated soda after 14 curing days is 6.5 and 6.1 times of pure soda respectively.

KEYWORDS: Soda waste, Fly ash, Lime, Compaction test, Unconfined compression test

1. INTRODUCTION

Soda is an important chemical material and being widely used in food industry, chemical industry, pharmaceutical industry and other areas. Soda waste is a kind of industrial waste which is produced in the process of soda ash production. This kind of soda waste is always drained off into sea after simple treatment or discharged to a specific area by pipelines (Yan Chi, 2008). However, these treatments cannot consume all the soda waste and significantly affect local ecology environment. Soda waste has become an urgent issue to be solved.

Many researchers have conducted many lab or field tests to search methods to reuse the soda waste. Huang (2000) used soda waste as chemical fertilizer to improve soil conditions. They were also used as additive in the production of cement, brick and other building materials (Sun and Yu, 1991). However, the consumption of soda waste used as chemical fertilizer or building materials is limited and the cost is high. Therefore, most factories tend to place soda waste in urban due to high cost in dealing with these soda wastes. However, the stack of soda wastes for long time may cause serious pollution to groundwater and ecological environment as the large amount of chloride and sulphate ions. In 1990s, soda waste was ever proposed to be mixed with soil and fly ash, and then used in reclamation in Japan. This method was estimated to be effective. After that, many studies have been reported on soda waste used as backfilling material mixed with soil (Yan et al., 2006; Yan et al., 2007; Xu et al., 2014; Kou et al., 2015). This method of mixing soda waste with some materials used as backfilling soil in engineering could largely consume the soda waste and the cost is relatively lower.

In this paper, two kinds of materials fly ash and lime are attempted to use as the added materials and mixed with soda waste to form the mixed soils. Then Compaction test and unconfined compression test are conducted to investigate the properties of mixed soils with different ratio and different curing times. It should be noted that all tests were conducted by using one type of soda waste, fly ash and lime.

2. EXPERIMENTAL DETAILS

The soda waste and fly ash used in this test are from Shandong Haihua Soda Factory, which located in Weifang City, Shandong Province of China. The lime used in this test was also from one factory in Weifang City. The chemical components of fly ash used in this test include 40% silicon dioxide (SiO_2), 20% aluminium oxide (Al_2O_3) and 5% calcium oxide (CaO). The main component of lime used in this test is calcium oxide (CaO). Firstly, the soda waste, fly ash and lime were dried in stove. Then the soda waste was mixed with fly ash and lime respectively according to predesigned ratios. The dry soda waste and fly ash were mixed together to form soda-fly(S-F) soil by the weight ratio of 5:5, 6:4, 7:3 and 8:2, respectively. The dry soda waste and lime were mixed together to form soda-lime(S-L) soil by the added ratio of 1%, 3%, 5%, 7% and 9%, respectively. Finally, laboratory compaction tests were conducted to determine the optimum water content and maximum dry density of S-F mixed soil. The optimum mixed ratio of soda waste and fly ash was also investigated in lab. Unconfined compression tests were conducted to determine the unconfined compression strength of S-L mixed soil.

3. TEST RESULTS AND DISCUSSION

Table 1 shows the chemical composition of soda waste used in this test. It is indicated that the main chemical component includes $CaCO_3$, $Mg(OH)_2$, and $CaSO_4$. These oxides are difficult to dissolve in water and the content is relative high. The left matter, such as NaCl and $CaCl_2$, are relative easy to dissolve in water and the content is relative low. In other words, these oxides can be used as the main component of mixed soil. This can support the possibility for soda waste mixture used as engineering soil in practical engineering. In this paper, the diameter of soda waste was determined using laser particle size analyser. The diameter distributions of soda waste are shown in Figure 1. The graph's horizontal axis shows the particle diameter and the unit is μm. The left vertical axis (q%) shows the volume percentage and the right vertical axis (Q%) shows the cumulative percentage of particle. It can be seen that the diameter distribution curve of soda waste is relative smooth and the diameter is between 0.5 and 70.0 μm. The percentage of soda waste with diameter of 0.5-10.0 μm is about 60 %. The percentage of soda waste with diameter of 10.0-35.0 μm is about 35.0 % and 5.0 % for diameter of 35.0-70.0 μm. This diameter distribution of soda waste implies that it is easy to be mixed with other material to form mixed soil.

Table 1 Chemical composition analysis of soda waste

Name	$CaCO_3$	$Mg(OH)_2$	NaCl	$CaSO_4$	Fe_2O_3
Content	51.22	12.78	10.87	9.24	5.23
Name	**$CaCl_2$**	**CaO_2**	**Others**	**Sum**	
Content	4.45	2.10	3.57	99.46	

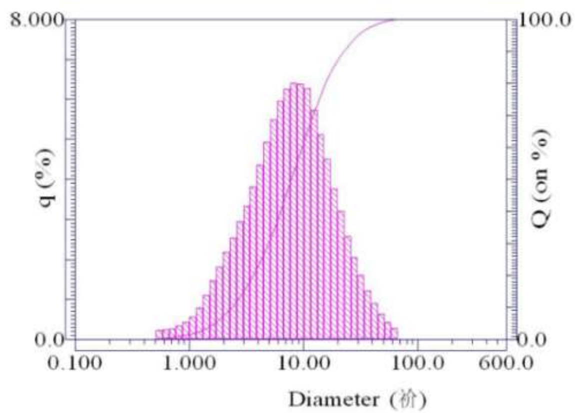

Figure 1 Diameter distribution of soda waste

3.1 Strength characteristics of S-F mixed soil

Soda waste and fly ash were mixed together according to the predesigned ratios after be dried in oven. Then lab compaction test was conducted to investigate the compaction behaviour of mixed soil. Figure 2 shows the compaction curve of S-F mixed soil with different ratios, namely the relationship of dry density and water content. Through the compaction curve, the optimum water content and maximum dry density of S-F mixed soil can be determined. It can be seen from the figure that the effect of fly ash content is significant to water content and dry density of soda waste. The water content of S-F mixed soil with different ratios ranges from 60 to 70 %, and the dry density is between 0.83 and 0.92. It also can be seen that the maximum dry density of S-F mixed soil with ratios 5:5 and 7:3 is bigger than that of 6:4 and 8:2. Considering consuming the soda waste as many as possible, the ratio of 7:3 is better as the optimum design ratio.

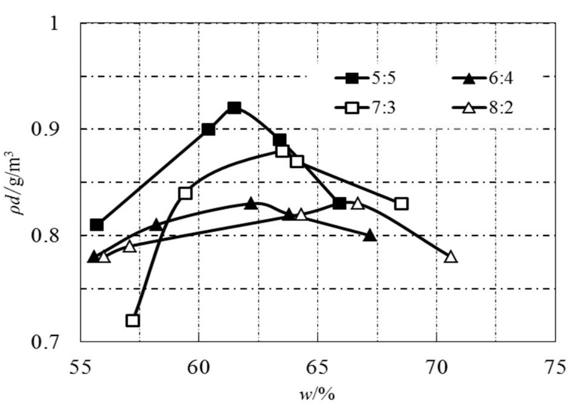

Figure 2 Compaction curves of S-F mixed soil with different ratio

The optimum water content of S-F mixed soil with 7:3 ratio can be obtained through lab compaction tests. The optimum S-F mixed soil can be prepared through mixing soda waste and fly ash with optimum water content of 63.5 %. Figure 3 shows the results of unconfined compressive test of pure soda waste and S-F mixed soil with optimum ratio of 14 curing days. The unconfined compressive strengthof pure soda waste with 14 curing days is about 0.04 MPa. The value for S-F mixed soil with optimum ratio is about 0.26 MPa, which is about 6.5 times of pure soda waste. It can be seen from the results that the unconfined compression strength of S-F mixed soil with optimum ratio is significant higher than that of pure soda waste. The S-F mixed soil with optimum ratio has potential advantage used as practical engineering soil.

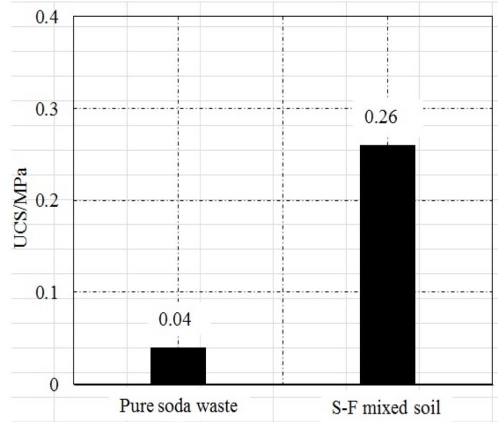

Figure 3 Unconfined compressive strength

3.2 Strength characteristics of S-L mixed soil

Lime also can be used as mixing material to improve the properties of fine granined deposits (Broms and Boman, 1975; Okumura and Terashi, 1975; Locat et al., 1990, 1996; Kou et al., 2005). This kind of treatment with lime has many advantages, such as increment in plasticity characteristics and strength behaviour with time (Kamon, 1992; Narasimha Rao and Rajasekaran, 1996). It is also indicated that the use of lime treated in fine-grained soils makes the system less sensitive in changing the stresses and other environmental factors (Kamon and Nontananandh, 1991; Sivapullaiah et al., 1998). Many civil engineers have realized this advantage and hence, in many situations, lime is perferred to improve the soil characteristics in civil engineering applications. Therefore, lime was also be used to mix with soda waste and attempt to improve the engineering properties of soda waste.

As presented in above section, the lime content of 1%, 3%, 5%, 7% and 9% were added into dry soda waste to prepare the specimens of S-L mixed soil. After 14 curing days, unconfined compression tests were conducted to investigate the unconfined compression strength of S-L mixed soil. The specimen pictures after unconfined compressive tests are shown in Figure 4. It can be seen that the failure model of specimen is different. This may be caused by different content of added lime. Figure 5 shows the strength curve of S-L mixed soil with lime percentage.. It can be seen from the figure that the effect of lime is significant to the strength behaviour of soda waste. With the lime content of 1-3%, the improvement magnitude of unconfined compressive strength was about 38.8-52.3 % than that of pure soda waste. The strength of S-L mixed soil increased to 0.241 MPa with the lime content of 3-7%. The increase magnitude is between 38.8-52.3 %. After the 7% of added lime, the strength of S-L mixed has little increment. It can be indicated that the optimum ratio of added lime is about 7 %.

Figure 4 Specimen failure model of S-L mixed soil

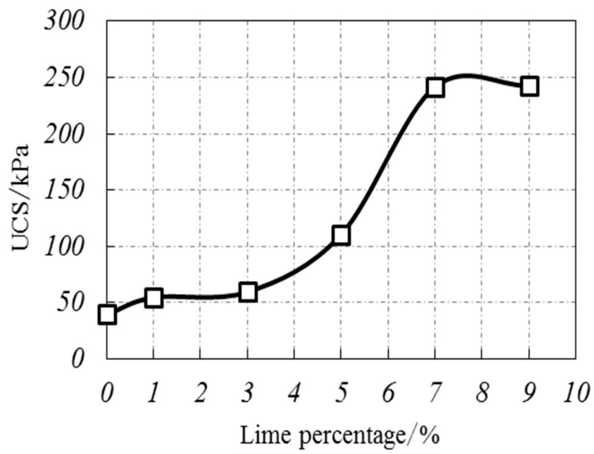

Figure 5 Unconfined compression strength curve vs lime content

4. CONCLUSION

This paper presented the properties of soda waste mixed with fly ash and lime, respectively. The unconfined compression strength of two mixed soils with different ratios was carefully investigated. The major conclusions can be summarized as follows:

1) The mechanical properties of pure soda waste are different from soils and cannot be directly used in engineering. However, the oxides in soda waste can supply the structure components for soda mixture used as engineering soil. The diameter distribution of soda waste also can supply potential to be used in engineering.
2) It is indicated that fly ash can significantly increase the strength of soda waste and the optimum ratio of soda waste to fly ash is 7:3. The optimum water content and maximum dry density of soda waste mixed with fly ash of 7:3 are 63.5% and 0.88. The unconfined compression strength of soda mixture with optimum ratio is about 6.5 times to pure soda waste after 14 days curing time.
3) Lime also can be used as additive for soda waste. The unconfined compression strength of soda waste mixed with 7% lime is the biggest. The unconfined compression strength of soda waste mixed with 7% lime is about 6.1 times to pure soda waste after 14 days curing time.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Broms, B., Boman, P., 1975. Lime stabilized columns. In: Proceedings of the 5th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangalore, India, vol. 1, pp. 227-234.

Huang, Zhihong. Technique on Farming Use about Soda Residues Polybasic Compound Fertilizer Containing Calcium and Magnesium. Soda Industry, 2000, (1): 20-22.

Kamon, M., 1992. Recent developments of soil improvement. In: Proceedings of International Symposium on Soil Improvement and Pile Foundation, Nanjing, China, vol. I, pp. 1-16.

Kamon, M., Nontananandh, S., 1991. Combining industrial wastes with lime for soil stabilization. J. Soil Mech. Found. Eng., ASCE 117, 1-17.

Kou, H, Guo W, Zhang M. 2015. Pullout performance of GFRP anti-floating anchor in weathered soil. Tunn. Undergr. Space Technol, 49: 408-416.

Kou, H, Chu J, Guo W, et al. 2015. Field study of residual forces developed in pre-stressed high-strength concrete (PHC) pipe piles. Can. Geotech., J. 53(4): 696-707.

Locat, J., Berube, M.A., Choquette, M., 1990. Laboratory investigations on the lime stabilization of sensitive clays: shear strength development. Can. Geotech. J. 27, 294-304.

Locat, J., Tremblay, H., Leroueil, S., 1996. Mechanical and hydraulic behaviour of a soft inorganic clay treated with lime. Can. Geotech. J. 33, 654-669.

Narasimha Rao, S., Rajasekaran, G., 1996. Reaction products formed in lime-stabilized marine clays. J. Geotech. Eng., ASCE 122, 329-336.

Okumura, T., Terashi, M., 1975. Deep-lime-mixing method of stabilization for marine clays. In: Proceedings of the 5th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangalore, India, vol. 1, pp. 69-75.

Sun, Gedong, YU Lixiu. Waste residue application in building gelation materials production. Soda Industry, 1991, (6): 1-4.

Sivapullaiah, P.V., Prasanth, P., Sridharan, A., 1998. Delay in compaction and importance of the lime fixation point on the strength and compaction characteristics of soil. Ground Improvement, 27-32.

Xu, Yulong, YANG Chunhe, CHENG Feng, et.al. 2014. Experimental study on one-dimensional settlement of alkali wastes backfilled to abandoned salt caverns. Chinese Journal of Geotechnical Engineering, 36(3):590-596.

Yan, Chi. 2008. Research on method of synthesis environment estimation and mechanism of strength for pure alkali residue. Tianjin: Tianjin University, 2008.

Yan, Shuwang, HOU Jinfang, LIU Run. 2006. Research on geotechnical properties and environmental effect of mixture of soda waste and fly ash. Rock and Soil Mechanics, 27(12): 2305-2308.

Yan, Chi, SONG Xukun, ZHU Ping, et al. 2007. Experimental study on strength characteristics of soda residue with high water content. Chinese Journal of Geotechnical Engineering, 29(11):1683-1688.