

Comparative study of engineering properties of two-lime waste tire particle soil and soil with lime/loess ratio of 3:7

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Abstract: This study describes an analytical comparison of the engineering characteristics of two-lime waste tire particle soil and soil with lime/loess ratio of 3:7 using density measurements, results of indoor consolidation tests, and direct shear tests to examine the strength and deformation characteristics. It investigates the engineering performance of collapsible loess treated with waste tire particles and lime. The results indicate that (1) the shear strength of the two-lime waste tire particle soils increases continuously with soil age; and (2) the two-lime waste tire particle soils are light-weight, strong, and low-deformation soils, and can be applied primarily to improve the foundation soil conditions in areas with collapsible loess soils. This could address the problem of used tire disposal, while providing a new method to consider and manage collapsible loess soils.

1. Introduction

Owing to the recent rapid development of the motor vehicle industry, waste tires have become a significant source of solid waste. Nearly all countries must encounter the challenge of obtaining different methods to dispose the used tires. If the tires are disposed in landfills, they do not decompose easily, and can cause fire hazards. If incinerated, they generate toxic gases. Therefore, geotechnical engineering experts worldwide have been trying to obtain methods to reuse the discarded tires. SEDA^[1] used them to improve the quality of expansive soils. MASAD^[2] mixed the discarded tires with sand for use as a light-weight filling material. ROWE^[3] discovered other uses for discarded tires. BLUMENTHAL^[4] demonstrated that discarded tires can be used to improve the surface of asphalt pavements.

BOSSCHER's^[5] research concluded that the discarded tires could be used to reinforce highway embankments. Deng An et al.^[6] discovered that adding 10–20% rubber particles to sandy soil can improve its shear strength. Zou Weilie et al.^[7] indicated that expansive soils mixed with 23% rubber particle content provides exceptional results. Xin Ling et al.^[8] indicated that the stress-strain curves of the soil mixed with rubber particles from discarded tires is similar to the stress-strain curve of remolded soil. Yang Zhao's^[9] experiment regarding seismic performance indicated that the magnitude of embankment acceleration magnification with rubber treated embankments was 32% lower compared with plain soil embankments. Li Lihua^[10] used large scale equipment to test the direct shear strength and study the bi-axial and tri-axial strength characteristics of expansive soil treated with discarded tires. The results indicated that the discarded tire treatment resulted in significant improvements in biaxial and triaxial strength, and the triaxial results improved considerably. Li Zhaohui et al.^[11] mixed the waste tire scraps with loess to study the density and strength characteristics of the mixture, and analyzed their application in highway road bed engineering.



In summary, while several significant studies have been conducted regarding the use of scrap tires in geotechnical engineering, relatively few studies have been conducted regarding their applications in collapsible loess soils. Currently, there is an increase in the amount of construction in loess soil environments, and thus, the demand for loess soil treatments is increasing. Lime additives cause excessive dust pollution; therefore, conventional lime treatments have limited applicability. Consequently, it is necessary to study the engineering characteristics of new types of composite materials for the treatment of loess soil foundations.

Two-lime waste tire particle soil refers to the composite material composed of lime and fly ash cement mixed with waste tire particles and loess. This study compares the deformation and strength characteristics of two-lime waste tire particle soils with soil with lime/loess ratio of 3:7. It aims to observe the engineering properties and potential of two-lime waste tire particle soils for treatment of collapsible loess soil. The findings could be used as a reference for engineering design and construction in loess soil environments.

2. Experimental materials

2.1. Loess and lime

The lime and loess used in this study were obtained from a construction site at a school in Qingyang, Gansu. The loess was disturbed soil obtained from excavation at a depth of 5.0 m. Its physical characteristics are listed in Table 1. The lime was fresh calcareous lime. The loess and lime were each filtered using a sieve with a 5 mm mesh.

2.2. Fly ash

The fly ash was obtained from a power plant. Its physical and mechanical properties are summarized in Tables 2–4.

Table 1 Physical properties of Loess

Parameter	Moisture content (%)	Maximum dry density (g/cm^3)	Specific gravity (d_s)	Liquid limit (w_L)	Plastic limit (P_L)	Plasticity index (I_p)	Collapse ratio coefficient (δ_s)	Initial bulk density (g/cm^3)
Loess	22.6	1.70	2.72	25.1	16.3	8.8	0.023	1.56

Table 2 Physical composition of fly ash

Index	Fineness%	Un-watered content%	Combustion loss%	Sulphur trioxide%	28-day compressive strength ratio%
Content	<10	<94	0.33–1.78	0.46–1.82	>82

Table 3 Mechanical properties of fly ash

Specific gravity d_s	Optimal water content w_{op}	Maximum dry density $\rho_{d\max}$	Curvature coefficient C_c	Average particle diameter d_{50}	Coefficient of unevenness C_u	Water content w	Natural density ρ
2.88	38.05	1.34	1.38	0.05	16.11	25.1	1.13

Table 4 Chemical properties of fly ash

Chemical	Fe_2O_3	Al_2O_3	SiO_2	SO_3	K_2O	Na_2O	CaO	MgO	Combustion loss
Content	2.63	27	61.52	1.85	2.95	0.06	1.93	0.86	1.2

2.3. Waste tire particles

The waste tire particles were purchased from a garbage recycling facility in Qingyang. After the steel

fibers were removed, the rubber was mechanically ground into small particles, as shown in Figure 1.



Figure 1 Waste tire particles

3. Preparation of soil samples and experimental methods

3.1. Equipment

The primary equipment used in the experiments included the following: Model JDS-2 digitally controlled electric compactor, Model ZJ strain-controlled direct shear test apparatus, Model WG single lever consolidometer, a ring knife, a 200 g range balance, and a 10 kg scale.

3.2. Preparation of soil samples

(1) After the lime soil and two-lime waste tire particle soils were prepared and mixed according to the volumetric ratios in Table 5, they were each compacted three times. The compacted samples were used in the experiment.

Table 5 Volumetric ratios of the samples

Original material	Volumetric compositions of materials (%)			
	Lime soil	Two-lime waste tire particle soil A	Two-lime waste tire particle soil B	Two-lime waste tire particle soil C
Lime	30	5	10	4
Fly ash	0	10	10	10
Waste tire particles	0	10	30	46
Loess	70	75	50	40

(2) To maintain realistic conditions, a 1.5 m deep, 3 m long, and 2 m wide hole was excavated in an open space. The compacted samples were then properly placed in the hole and buried. Figure 2 shows a test sample.



Figure 2 Two-lime waste tire particle test sample

3.3. Steps

(1) The samples of soil with 3:7 lime/loess ratio and two-lime waste tire particle soils A, B, and C (waste tire particle contents of 10%, 30%, and 46%, respectively), aged 7, 10, 14, 28, and 56 days were weighed, and their densities were calculated.

(2) Subsequently, the 14-day old samples were used in the consolidation test as shown in Figure 3.

(3) Each of the samples was subjected to a direct shear test under a pressure of 300 kPa.



Figure 3 Consolidation test

(4) The testing procedure was finished, and the test data were collected.

4. Analysis of test results

4.1. Density characteristics of two-lime waste tire particle soil

The density of three samples of each material for each age was measured. The average of the three measurements demonstrated the relationship between the sample age and density, as shown in Figure 4. We can observe in the figure that as the samples age, the density of the two-lime waste tire particle soils and the lime soil gradually decreases. This is because the water content of the samples decreases with time. However, at any particular time, the density of soil with lime/loess ratio of 3:7 is higher than the density of all the two-lime waste tire particle soils. This means that a given volume of two-lime waste tire particle soil will be lighter than the same volume of lime soil.

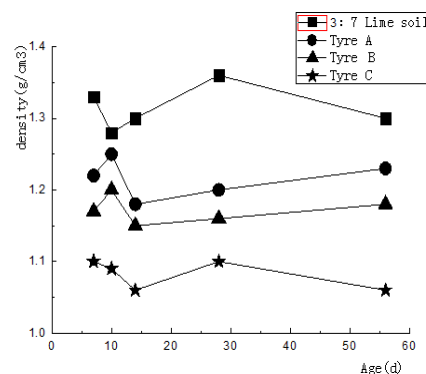


Figure 4 Soil sample density vs. age

4.2. Strength characteristics of two-lime waste tire particle soil

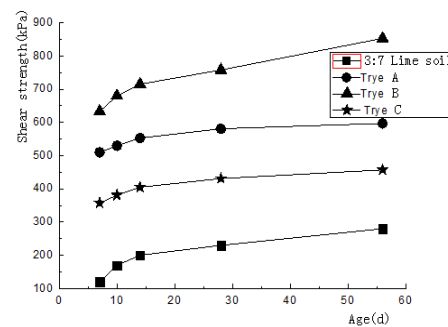


Figure 5 Soil sample shear strength vs. age

The direct shear tests of all samples were conducted using a controlled normal stress of 300 kPa. The results are shown in Figure 5.

Figure 5 indicates that the shear strength of all samples increases with age, but the two-lime waste tire particle soils have higher shear strength than the lime soil. The two-lime waste tire particle soil B exhibited the highest shear strength and the highest rate of increase i.e., the strength of the sample with the loess to lime ratio of 5 increased rapidly with age.

4.3. Deformation characteristics of two-lime waste tire particle soil

Figure 6 illustrates the subsidence of each of the samples vs. time under 300 kPa controlled normal stress conditions.

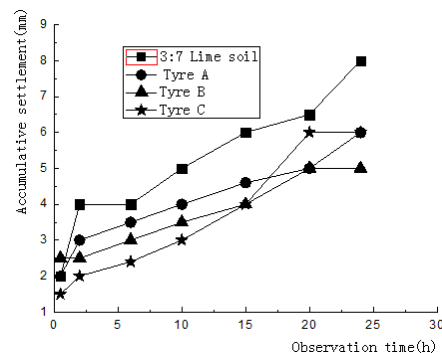


Figure 6 Subsidence vs time for each type of soil (age 14 days)

Figure 6 indicates that the overall subsidence increased over time for all samples. However, the total subsidence of the two-lime waste tire particle soils was less than the subsidence of the soil with lime/loess ratio 3:7, for all cases. Therefore, the deformation of the two-lime waste tire soils is less than the deformation of the lime soil.

5. Conclusions

(1) With the aging of the samples, the density of the two-lime waste tire soil and the lime soil samples gradually decreased.

(2) With the aging of the samples, the shear strength of the two-lime waste tire particle soils constantly increased. However, the shear strength of the two-lime waste tire particle soil with a soil to lime ratio of 5 increased rapidly.

(3) The two-lime waste tire particle soils are light-weight, strong, and low-deformation soils that could be widely used to improve building foundations in collapsible loess soil environments. This would not only solve the used tire waste problem, but would also provide a new method to consider

and manage collapsible loess soils.

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References

- [1] SEDA J H, LEE J C, CARRARO A H. Beneficial use of waste tire rubber for swelling potential mitigation in expansive soils[C]//Geotechnical Special Publication. Reston: American Society of Civil Engineers, 2007: 1–9.
- [2] MASAD E, TAHA R, HO C, PAPAGIANNAKIS T. Engineering properties of tire soil mixtures as a lightweight fill material[J]. Geotechnical Testing Journal, 1996, 19(3): 297–304.
- [3] ROWE R K, MCLSAAC R. Clogging of tire shreds and gravel permeated with landfill leachate[J]. Journal of Geotechnical and Geoenvironmental Engineering, 2005, 131(6): 682–693.
- [4] BLUMENTHAL M, ZELIBOR J. Scrap tires used in rubber-modified asphalt pavement and civil engineering applications[C]//Utilization of Waste Materials in Civil Engineering Construction. New York: American Society of Civil Engineering, 1993: 182–201.
- [5] BOSSCHER P J, EDIL T B, KURAOKA S. Design of highway embankments using tire chips[J]. Journal of Geotechnical and Geoenvironmental Engineering, 1997, 123(4): 295–304.
- [6] Deng A, Feng J R. Effect of scrap tire bead addition on shear behavior of sand[J]. Journal of PLA University of science and Technology (natural science Edition), 2009, 10(5): 483–487. (in Chinese)
- [7] Zou W L, Xie P, Ma Q T, et al. Experimentation on characteristics of expansive soil modified with waste tire rubber particles[J]. Journal of Sichuan University (Engineering science Edition), 43(3), 2011, 44–48. (in Chinese)
- [8] Xing L, Liu H L, Shen Y. et al. Unconfined compressive test of lightweight soil mixed with rubber chips of scrap tires [J]. Journal of PLA University of science and Technology (natural science Edition), 2010, 11(1): 79–83. (in Chinese)
- [9] Yang C. The seismic properties of waste tire reinforced embankment [D]. Hubei University of Technology. 2015. (in Chinese)
- [10] Li L H, Cui F L, Xiao H L. et al Shear comparison of waste tyres and biaxial/triaxial geogrid reinforced soil[J]. Yellow river. 2016, 38(2), 117–120. (in Chinese)
- [11] Li Z H, Zhang H Y, Zhao Y X. Engineering properties of tire shreds reinforced soils[J]. Geotechnical Investigation & Surveying. 2009, 6, 19–23. (in Chinese)