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[6] used them to improve the quality of expansive soils. MASAD[5] 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.

| Parameter | Moisture content (%) | Maximum dry density (g/cm³) | Specific gravity (dₜ) | Liquid limit (wₐ) | Plastic limit (P₉) | Plasticity index (Iₚ) | Collapsibleity coefficient (δₛ) | Initial bulk density (g/cm³) |
|-----------|----------------------|----------------------------|----------------------|------------------|------------------|----------------------|-----------------------------|----------------------------|
| Loess     | 22.6                 | 1.70                       | 2.72                 | 25.1             | 16.3             | 8.8                  | 0.023                       | 1.56                       |

| 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                               |

| Specific gravity ds | Optimal water content wₒ | Maximum dry density ρₒ | Maximum Curvature coefficient Ce | Average particle diameter dₕ₀ | Coefficient of unevenness Cu | Water content w | Natural density ρ |
|---------------------|---------------------------|------------------------|-------------------------------|-------------------------------|---------------------------|----------------|-----------------|
| 2.88                | 38.05                     | 1.34                   | 1.38                          | 0.05                         | 16.11                     | 25.1           | 1.13            |

| Chemical | Fe₂O₃ | Al₂O₃ | SiO₂ | SO₃ | K₂O | Na₂O | 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.

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.

| 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.
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.

(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.

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

Acknowledgments
Funding: Gansu Province Higher Education Scientific Research Project (2016A-084)

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