Shear Strength Characteristics of Loess Reinforced with Tire Derived Aggregate

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***Abstract*—The Application of waste tyres in Civil Engineering is nearly 30 years. This study investigates the engineering properties of tire derived aggregate (TDA) reinforced loess and presents the strength properties of loess incorporating TDA as a reinforcement. The objective of this paper is to evaluate the effect of TDA (10mm-80mm) content and TDA aspect ratio on shear strength behavior of loess mixture. The direct shear tests was performed on the samples with loess containing 0%, 10%, 18%, 33%, and 100% of the TDA by weight of soil mixtures, and 4 TDA aspect ratios respectively. The test results showed a well-defined peak shear strength for specimens of pure loess and low TDA content (less than 18%) under low normal stress (less than 96 kPa). No peak value were found for all specimens under high normal stress (144kPa). The optimum TDA content was approximately 10% (by weight) which led to the maximum shear strength. For a given TDA content, increasing the TDA aspect ratio led to increasing shear strength. The study concludes that the use of TDA modified loess in the backfills and embankments is possible.**

Keywords*—*tire derived aggregate; shear strength; content; aspect ratio; loess

I. INTRODUCTION

Tire derived aggregates (TDA) are not toxic solid waste [1-2], and can be widely used in civil engineering construction because of its low unit weight, free drainage, high thermal insulation, vibration damping and so on. Previous studies focus on the use of tire shred-sand composites as backfill materials for geoengineering applications [3-8]. Relatively few studies have focused on fine- grained soils [9-10]. Akbulut, S., Arasan, S., and Kalkan, E. (2007) performed tests using different clays and strips of rubber tire with different lengths. The results showed that the presence of shredded rubber tires increased the apparent cohesion of the material while increasing the friction angle. Cetin H, Fener Mand, Cunaydin O. (2006) stated that as the rubber content increased up to 40%, the cohesion of the soil-rubber mixture increased while the friction angle decreased. This study seeks to optimize the quantity, size, and shape of TDA to be used as reinforcement in loess for enhanced embankment performance.

II. MATERIALS AND METHODS

A. Materials

The loess was locally obtained from the Baihu mountain formation of Quaternary age outcropping in the Yuzhong basin in northwest of China. The main ingredient of the loess is clay classified as CL based on the Unified Soil Classification System (USCS), detailed in ASTM D 422 [11], showed in Figure. I. The specific gravity of loess is 2.70, liquid limit is 26.7%, plastic limit is 18.9%, plasticity index is 7.8%, maximum unit weight is 1.7g/cm3, and optimum water content is 15.2%.

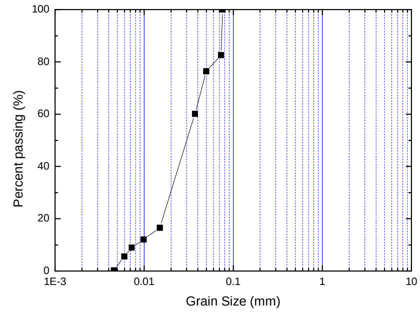

FIGURE I. SIZE DISTRIBUTION OF LOESS

The TDA were made form shredded tires with controlled rectangular sizes to achieve width of 10mm (dimension) and lengths of 10mm, 20mm, 40mm, and 80mm. The aspect ratios of the TDA used in tests were 1, 2, 4, and 8 (Figure II). The TDA were made by manually cutting automobile tires into uniform tire chips and tire shreds. The specific gravity of TDA is 1.147, and the absorption is 1.07~1.08% when immersed in water at room temperature for a period of 24 hours per ASTM C 127-04 [12].

FIGURE II. PHOTO OF TDA

B. Specimen Preparation

The TDA samples was compacted in three layers in box by tamping using a steel rod, with a bulk density of 0.49 g/cm^3, which is in good agreement with results obtained from previous reports, i.e. bulk density values range from 0.4g/cm3-0.75g/cm^3[13-16]. Pure loess passing from No.4 seize at the optimum water content was placed in three layers into the shear box of 305mm by 305mm by 200mm. Each layer was compacted by 490 blows of a 24.4N (5.5 lbf) rammer dropped from a distance of 305 mm (12 in.), subjecting the soil to a total compactive effort of about 600 kN · m/m^3 (12 400 ft-lbf/ft3). Specimens of loess containing 10%, 18%, and 33% of TDA by weight of soil mixtures were compacted like pure loess. The details of specimens are presented in Table I.

TABLE I. DETAILS OF SPECIMENS

series	TDA content χ (% by weight)	TDA content of dry soil χ' (% by weight)	TDA content α_v (by volume)	TDA width (mm)	TDA aspect ratio η	Bulk density (g/cm^3)
1	0	0	0	na	na	1.958
2	10	11.52	23.46	10	4	1.876
3	18	20.73	38.11	10	1	1.711
4	18	20.73	38.11	10	2	1.732
5	18	20.73	38.11	10	4	1.729
6	18	20.73	38.11	10	8	1.716
7	33	38.01	59.08	10	4	1.435
8	100	100	100	10	4	0.488

Note: Bulk density, specimens compacted under standard effort in shear box

C. *Test Program and Procedures*

The direct shear specimens were prepared with an area of 305mm by 305mm, and a height of 200mm and tested in a ShearTrac-III load frame. A total of 8 series direct shear tests were performed under unsaturated conditions using a faster shear rate (0.8mm/minute) in general accordance with ASTM standard method D 3080-03 (ASTM 2003) [17].Each series included four tests conducted under normal pressures of 24, 48, 96, and 144kPa (or 500, 1000, 2000, and 3000 1b/ft^2) to simulate overburden consolidating pressures. For a test specimen, Failure was taken to correspond to the maximum shear stress attained, or shear stress at 15% relative lateral displacement. For each test series, conventional shear strength parameters (cohesion intercept and friction angle) and the equivalent friction angle was estimated in this study. The equivalent friction angle is the imaginary internal friction angle taking into account the cohesion.

III. RESULTS AND DISCUSSION

A summary of the conventional Mohr-Coulomb shear strength parameters and the equivalent friction angles is shown in Table II.

The shear strength at failure verses TDA content under different normal stress are shown in Figure. 3. As seen from the curves, there is a clear increase in failure shear stress up to 18% TDA mixtures under normal stress range from 24kPa to 96kPa. But 10% TDA mixtures shows a nuanced increasing under 144kPa normal stress. Also, the failure shear stress increase as the normal stress increase.

The failure envelops, the cohesion and friction angle derived from Mohr-Coulomb failure criterion versus TDA content are shown in Figure IV and V.

As seen from figure V, Cohesion, and friction angle, increase as TDA content increase up to 18% and 10% respectively, while the equivalent friction angle increase as TDA content increase up to 10%.

TABLE II. SUMMARY OF SHEAR STRENGTH PARAMETERS

series	TDA content χ (% by weight)	TDA aspect ratio η	$\sigma \le 144kP_a$ c (kPa)	$\sigma \le 144kP_a$ φ (°)	$\sigma \le 144kP_a$ R^2	$\sigma \le 96kP_a$ c (kPa)	$\sigma \le 96kP_a$ φ (°)	$\sigma \le 96kP_a$ R^2	φ_{eq} (°)
1	0	na	44.86	43.74	0.985	40.60	46.39	0.972	55.80
2	10	4	52.46	44.79	0.982	48.58	59.65	0.962	65.69
3	18	1	37.40	48.00	0.997	36.37	48.50	0.993	56.47
4	18	2	42.52	48.40	0.985	35.10	52.21	0.987	58.86
5	18	4	69.06	40.30	0.995	65.20	43.07	1.000	58.22
6	18	8	65.90	35.40	0.821	43.23	50.00	0.994	58.66
7	33	4	50.81	30.45	0.901	37.85	41.05	0.996	51.67
8	100	4	7.43	17.50	0.992	5.75	19.44	0.997	22.43

Note: The Normal stress of 96kPa is used to calculate the equivalent friction angle; R^2 is the correlation factors of conventional Mohr-Coulomb shear strength parameter.

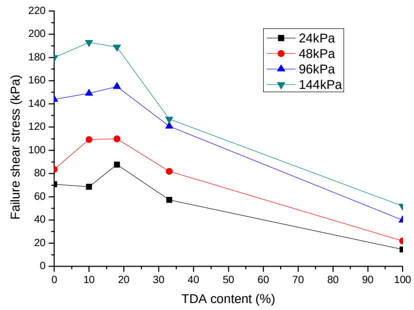

FIGURE III. FAILURE SHEAR STRESS VERSUS TDA CONTENT

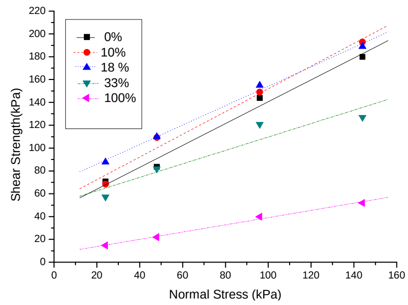

FIGURE IV. FAILURE ENVELOPES FOR SERIES WITH VARYING TDA CONTENT

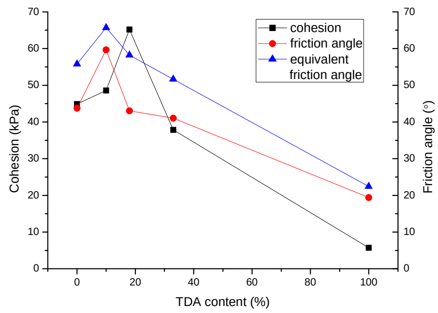

FIGURE V. CHANGE OF COHESION, FRICTION ANGLE, AND EQUIVALENT FRICTION ANGLE WITH TDA CONTENT INCREASE

In other words, it is difficult to derive optimum TDA content for increasing shear strength by comparing cohesion and friction angle respectively. For example, the cohesion of

18% TDA mixtures (65.20kPa) is much bigger than that of 10% TDA mixtures (48.58kPa), while the friction angle of 18% TDA mixtures (43.07°) is less than that of 10% TDA mixtures (59.65°). The use of equivalent friction angle allows a straightforward comparison of the effect on shear strength of variables such as TDA content, and TDA aspect ratio. Figure. 5 shows that the optimum TDA content is 10% which makes a peak equivalent friction angle of 65.69°. As seen here, When the content of TDA exceeds 33%, the shear strength of the mixtures will be lower than that of pure compacted soil.

The failure shear stress and TDA aspect ratio relation ships are shown in Figure. 6. From Figure.6 it can be seen that there has a clear peak failure shear stress of 4:1aspect ratio under low to moderate normal stress (less than 48 kPa), while the failure shear stress increases first at 2:1 aspect ratio and then decreases with increasing aspect ratio under high normal stress (144kPa). The failure envelops, the cohesion and friction angle derived from Mohr-Coulomb failure criterion versus TDA aspect ratio are shown in Figure VI and VIII.

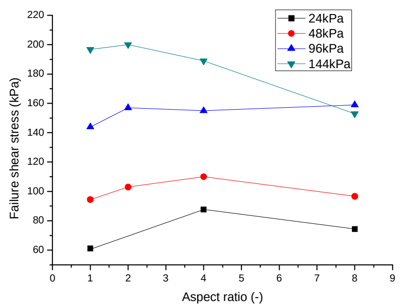

FIGURE VI. FAILURE SHEAR STRESS VERSUS TDA ASPECT RATIO

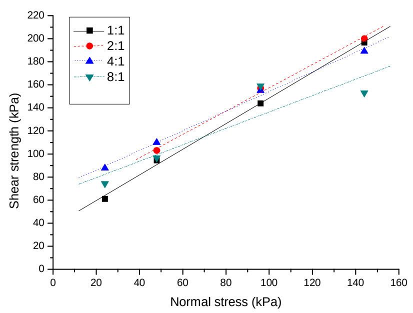

FIGURE VII. FAILURE ENVELOPES FOR SERIES WITH VARYING TDA ASPECT RATIO

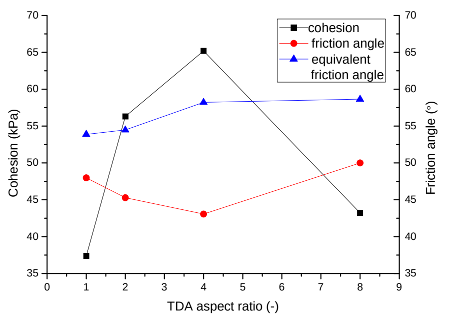

FIGURE VIII. CHANGE OF COHESION, FRICTION ANGLE, AND EQUIVALENT FRICTION ANGLE AS TDA ASPECT RATIO

As seen from Figure VIII, the cohesion and equivalent friction angle have a peak value corresponding of 4:1, and 8:1 aspect ratio. The reason that the 8:1 aspect ratio sample has the maximum friction angle value is because of much lager size of this kind of TDA (8cm) creating more friction, and showing nonlinear behavior. Curve of equivalent friction angle shows samples with 4:1 aspect ratio creating bigger values than that of others. Figure. 8 shows that the cohesion increases with aspect ratio increase before 4:1, while the friction angle decreases. The cohesion decreases with aspect ratio increasing when aspect ratio exceeds 4:1, while the friction angle increases with aspect ratio increasing. In engineering application, if more attention is paid to the cohesion enhancement of back fill materials, the 4:1 TDA aspect ratio should be adopted. Big TDA aspect ratio (8:1) can reduce cost of processing waste tires, while also having high strength.

IV. CONCLUSIONS

An experimental testing program involving pure compacted loess, pure TDA, and TDA-loess specimens was under taken to evaluate the optimum TDA content and aspect ratio to be used in TDA reinforced loess. Evaluation of the experimental results obtained in this study led to the following conclusions:

The direct shear test results of pure compacted loess, TDA content of 10-18% TDA-loess specimens show a strain softening behavior, which show well defined peak shear strength. This response is significantly different from that of compacted loess, and TDA-loess mixtures which show a strain hardening behavior under medium to high normal stresses (96-144kPa).

The influence of TDA content on shear strength is significant. The shear strength of TDA-loess mixtures increases with increasing TDA content, reaches a maximum for a TDA content value in the vicinity of 10% to 18%, and then decreases for TDA contents beyond this value. The shear strength of 33% TDA content mixtures is lower than that of pure compacted loess. Accordingly, compacted loess can particularly benefit of 10% to 18% TDA.

The shear strength of TDA-loess mixtures increases with increasing aspect ratio under low to medium normal stresses (24-96kPa). This increasing in shear strength was particularly significant when the aspect ratio was increased from 4 to 8, which equivalent friction angles were 58.22°, and 58.66° respectively. On the other hand, under high normal stress (144kPa), the shear strength of TDA-loess mixtures increases with increasing TDA ratio, reaches a maximum for a TDA aspect ratio of 2, and then decreases for TDA aspect ratios beyond this value. Consequently, a structure under low to medium normal stresses (24-96kPa), TDA should be tailored with large aspect ratios.

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