Evaluation of Tensile Strength of Cement-Treated Soil Based on Laboratory Tests

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Abstract. Tensile strength and unconfined compressive strength of cement-treated soil are crucial mechanical parameters in soil stabilization by the cement mixing method. Although the unconfined compressive strength of soil-cement mixture has been well-documented, tensile strength has not received much concern. The purpose of this paper is to study the tensile strength of cement-treated soil using Portland Cement Blended PCB 40 and figure out the relationship between these two parameters. Totally, 54 soil-cement specimens were prepared with different cement-soil ratios (i.e., C/S = 10%, 15%, 20%) and stored at room temperature under air-humid condition. The results of laboratory Brazilian tests and unconfined compression tests show that the average ratio of tensile strength and unconfined compressive strength corresponding to the air-humid curing condition is about 0.08. There is not much difference in the ratio of the tensile strength to the unconfined compressive strength regardless of cement-soil ratio with curing time. The tensile strength achieved 0.78 MPa with a cement content of 20% at a curing day of 15 days.

Keywords: Cement-treated Soil · Unconfined Compressive Strength · Tensile Strength · UCS Test · Brazilian Test

1 Introduction

Portland cement is widely used in soft soil stabilization, in Vietnam and worldwide, due to its effectiveness in the improvement of soil-bearing capacity and convenience in construction operations. There are publications on this topic [5–9, 12]. Soil-cement mixtures, unlike soils, may be able to sustain some tensile stresses. Nguyen (2009) studied the influence of the cement-soil ratio on the tensile strength of soil cement mixing after 28 days of curing time. Because soil properties vary in a wide range from site to site, the properties of the soil-cement mixture also vary accordingly. The application of the

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empirical relations between tensile strength and unconfined compressive strength, which have been proposed in the world, to the soil-cement mixture in Vietnamese conditions may further amplify the errors. In addition, research on the tensile strength of soil-cement mixing and the relationship between tensile strength and unconfined compressive strength of soil-cement mixing is still limited in Vietnam. This paper aims to figure out the tensile strength and propose the relationship between the tensile and unconfined compressive strength of the soil-cement mixing by carrying out unconfined compressive tests and Brazilian tests on 54 soil-cement specimens, using Portland Cement Blended PCB 40, at different cement-soil ratios (i.e., C/S) with 10%, 15%, and 20%. After the mixing procedure, all the specimens were stored at room temperature under air-humid condition.

2 Methods and Implementations

2.1 Materials

The soil used for the mixing was fine yellow dry sand, a type of fill soil. Particle size distribution, carried out by dry sieving, according to ASTM D422–63 [4], as shown in Fig. 1, was uniformly graded with particle size varying in a wide range of 0.075 mm to 4.75 mm. As stated by USCS (Unified Soil Classification System-ASTM D2487-83) [2], the soil is classified as poorly graded sand (SP).

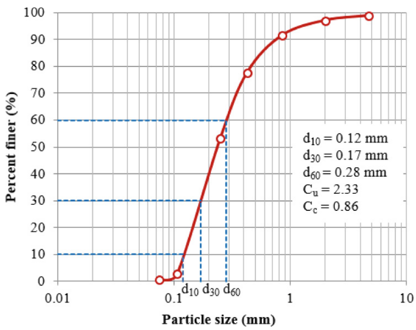

Fig. 1. Grain size distribution of soil

The cement used for the mixing was Portland PCB40. The basic properties of this cement are shown below in Table 1.

2.2 Procedure of Mixing and Curing Condition

Soil-cement specimens consisted of cement, soil, and water and were prepared with different cement-soil ratios (C/S). The cement content, i.e., C/S, is defined as the weight of dry cement divided by the weight of dry soil (e.g., 10%, 15%, 20%). Firstly, soil and cement were put in a mixer and dry-mixed for 15 min with two mixing modes such as surrounding mode (7.5 min) and bottom mode (7.5 min). Then, water was added to the

Table 1. Cement properties (after TCVN 6260: 2009) [10]

Compressive strength (MPa)		Setting time (minutes)		Fineness (*) (%)	Volume stability (mm)	SO_3 content (%)
3 days	28 days	Start	End			
≥18	≥40	≥45	≤420	≤10	≤10	≤3.5

*Defined as the fraction retained on the 0.09 mm pore-size sieve

mixture and continued mixing for 6 min (e.g., 3 min in the surrounding mode, followed by 3 min in the bottom mode) after TCVN 9403:2012 [11]. It should be noted that the water-dry soil ratio for all specimens is 22%. The amount of added water was calculated from the water content of sand at the field corresponding to the saturation degree of 85%. It is also assumed that the dry unit weight of sand is 15.7 kN/m^3 (i.e., 90% of the maximum dry unit weight derived from the standard compaction test).

A mold made of the cylindrical plastic pipe (PVC, 60 ±2 mm in diameter and 120 ±2 mm in height) was used for casting soil-cement specimens for the UCS test (ASTM D2166-00) [1]. The mold, which was sealed at one end, was filled with three layers of soil cement paste. Each layer was stamped 15 times on a wooden base to compact it. The mold was then covered and turned upside down while being stamped 15 times.

For the Brazillian test, cylindrical plastic containers with 60 mm in diameter and 30 mm in height were used as a mold (ASTM D3967-95a) [3]. Put the soil-cement paste into the mold which is sealed on one side and oily-coated inside, and regularly stamp it for 30 times.

Totally, 54 soil-cement specimens including 27 specimens for the Brazillian test and 27 specimens for UCS tests were prepared in this study. All 54 specimens are stored at room temperature under air-humid condition for 8, 15, and 29 days. After a curing period, specimens are extracted from the container by splitting a line on it, using a thumb to push the specimen gently and the cement-soil specimen will be slipped out of the mold. Then, the height and diameter of the specimens were measured.

2.3 Laboratory UCS and Brazilian Testing

The UCS test followed the standard ASTM D2166-00 [1]. After the specimen was placed at the center of the compression platform, adjust the loading device carefully so that the upper platen just makes contact with the specimen surface. Continuously increase the load at a loading speed of 1.0 mm/min until failure. The vertical displacement and axial force were measured by using a LVDT displacement transducer with measuring ranges from ±25 mm and a load cell with a capacity of 30 kN respectively. Figure 2a shows a specimen at failure in the UCS test with C/S of 15% and curing time of 15 days.

The Brazilian test follows standard ASTM D3967-95a [3]. In this test, the specimen was subjected to a uniform vertical line load diametrically with the 0.5 mm/min load until failure. The vertical displacement and axial force were measured by using two LVDT displacement transducers with measuring ranges from ±25 mm and a load cell with a capacity of 5 kN respectively. Figure 2b shows a specimen at failure in the Brazilian test with C/S of 15% and curing time of 15 days.

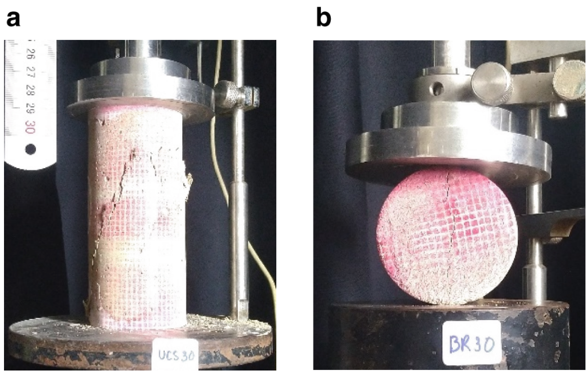

Fig. 2. **a** Specimen at failure in the UCS test with C/S of 15% and curing time of 15 days. **b** Specimen at failure in the Brazilian test with C/S of 15% and curing time of 15 days

3 Test Results and Discussions

3.1 Test Results

Unconfined Compressive Strength

The relationship between the unconfined compressive strength and curing time corresponding to 3 different ratios (C/S) 10%, 15%, and 20% is shown in Fig. 3a, where it can be seen that the unconfined compressive strength increases with the curing time. This is due to the cement hydration.

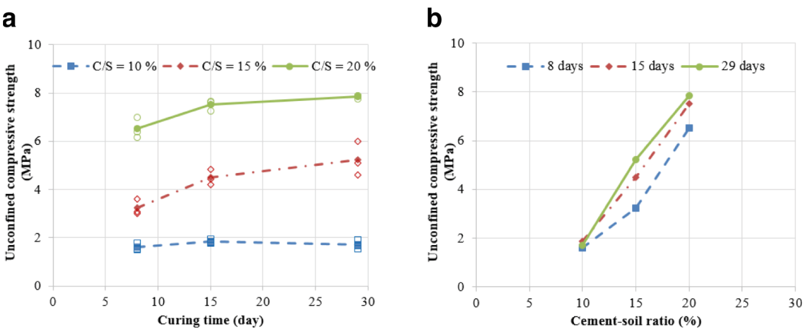

Fig. 3. **a** Variations of unconfined compressive strength with curing time. **b** Variations of unconfined compressive strength with cement-soil ratio

The unconfined compressive strength of soil-cement specimen increases significantly with increasing in the cement-soil (C/S) ratio, Fig. 3b. In addition, the unconfined compressive strength at 15 days of curing gets close to the corresponding strength at 29 days of curing.

In general, elastic modulus E_{50} increases in accordance with curing time for different cement-soil ratios, except for C/S = 10% the E_{50} tends to decrease with curing time, Fig. 4a. The reason may be during the tests, the contact between the specimen surface and the loading platen was not adjusted appropriately. From Fig. 4b, it can be seen that E_{50} steadily increases with cement-soil ratios of 10%, 15%, and 20%.

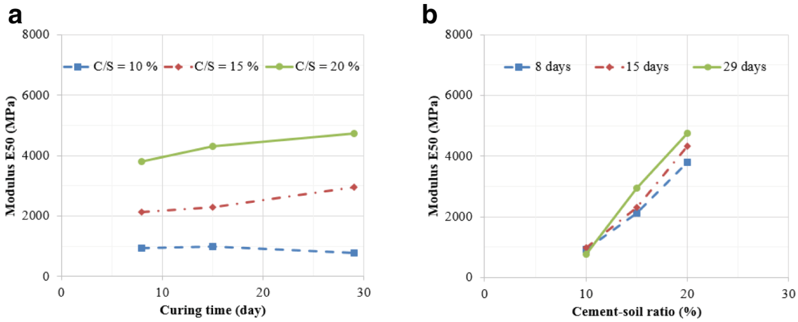

Fig. 4. **a** Variations of E_{50} with curing time. **b** Variations of E_{50} with cement-soil ratio

Tensile Strength

Figure 5a shows how curing time corresponding to the cement-soil ratios of 10%, 15%, and 20% affects the tensile strength. The tensile strength increases with curing time, in period of 8 days to 15 days of curing. The values of tensile strength after 29 days are slightly smaller than those after curing 15 days. The reason may be due to the drying of the specimens and the appearance of small cracks during curing the specimens in the air. There has been a significant increase in tensile strength with the cement-soil ratio as in Fig. 5b. The tensile strength is at peak for C/S = 20% at 15 days curing reached 0.78 (MPa).

Variations of the Ratio of Tensile Strength and Unconfined Compressive Strength

The ratio of tensile strength and unconfined compressive strength (denoted as TS/UCS) for all C/S values gradually decreases with the curing time described in Fig. 6a. The average ratio for all specimens is 0.08, in other words, the tensile strength is 0.08 times unconfined compressive strength.

At the same C/S value, the TS/UCS ratio decreases with curing time which can be explained that the longer the curing time is, the stronger the cement hydration reacts, leading to significantly higher unconfined compressive strength but the tensile strength enhances slightly. Therefore, the TS/UCS ratio decreases.

The TS/UCS ratios of 8 days, 15 days, and 29 days of curing increase slightly with the cement-soil ratio, Fig. 6b. However, for 29 days of curing the ratio decreases due to

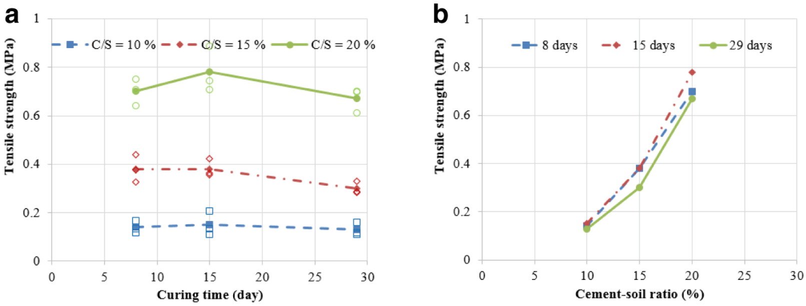

Fig. 5. **a** Variations of tensile strength with curing time. **b** Variations of tensile strength with cement-soil ratio

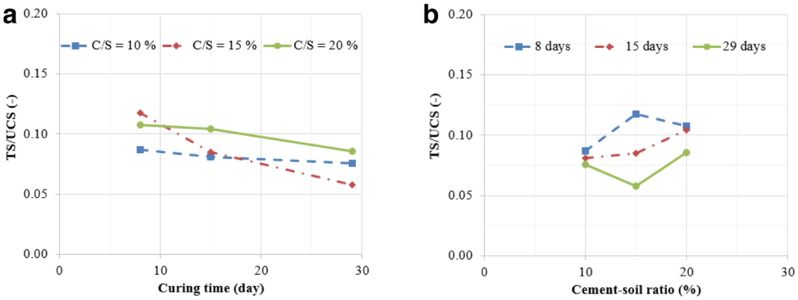

Fig. 6. **a** Variations of TS/UCS with curing time. **b** Variations of TS/UCS with cement-soil ratio

error in experiment operation or uneven mixing. In general, the more the cement content, the higher the TS/UCS value.

3.2 Discussions

The TS/UCS value of 0.08 from this study is not much different from the ones studied by Clough W (i.e., 0.10) and Consoli N (i.e., 0.15) [5, 6]. This result indicates that the tensile strength of cement-treated soil is significantly lower than the unconfined compressive strength.

Based on available publications the elastic modulus increases with curing time, the result of this study confirms again that statement. However, Fig. 4a shows that at 29 days of curing for C/S of 10%, the E_{50} decreased. This may be due to heterogeneous specimens, and unsmooth specimens' surfaces which affect the load's impact on these surfaces.

Correlations between UCS, TS, E_{50}, and C/S are established. The results show that R^2 values are very high, in other words, the correlations are considered strong shown in Table 2.

Table 2. Correlations between UCS, TS, $E_{50,}$ and C/S ratio

No.	Correlation	R^2
1	$UCS = 0.56 \times (C/S) - 3.90$	0.94
2	$TS = 0.058 \times (C/S) - 0.46$	0.96
3	$E_{50} = 338.91 \times (C/S) - 2536.40$	0.95

Note UCS (unconfined compressive strength, MPa), C/S (cement-soil ratio, %), E_{50} (modulus E_{50}, MPa), TS (tensile strength, MPa)

4 Conclusions and Recommendations

Based on the result of the UCS test and Brazillian test on 54 soil-mixing specimens with different C/S ratios (i.e., 10%, 15%, and 20%), the following conclusions can be drawn:

- Unconfined compressive strength steadily increases when cement content and curing time increase. Compared to curing time, the C/S ratio shows a clearer influence on the unconfined compressive strength. The maximum value of unconfined compressive strength is 7.8 MPa with a cement content of 20% after 29 days of curing.
- Modulus E_{50} greatly depends on the cement-soil ratio. E_{50} value has increased and reached 4746.6 MPa for C/S = 20% and 29 days curing.
- Tensile strength greatly increases with cement content but does not increase much (even decrease) with curing time. The maximum amount of tensile strength is 0.78 MPa, with 20% of cement content at a curing time of 15 days.
- The ratio of tensile strength and unconfined compressive strength decreases if the cement content in specimens increases. The average value of this ratio is about 0.08.

In this paper, only air-humid curing condition was considered. Because the enhancement of low-bearing soil in real-life situations does consider soil-cement specimens in submerged curing conditions, further studies should be done for the underwater curing condition.

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