Effect of Wood Fiber on the Strength of Calcareous Sand Rapidly Seeped by Colloidal Silica

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Abstract: Silica nano-particles are suspended in the colloidal silica and can be induced to gradually gel after the PH value changes. Thus colloidal silica can be utilized to rapidly seep through loose calcareous sand, and the silicon gel is gradually formed to bond sand particles. However, based on observation by scanning electron microscope(SEM), there are a lot of microcracks in the silica gel, which reduces the strength of the sand-gel composite. Therefore, in order to suppress crack growth, wood fibers are dispersed in the colloidal silica which still can seep through calcareous sand. 18 silicon-gel stabilized sand samples were prepared for tri-axial tests, where the concentration of colloidal silica is 20%, and wood fiber concentrations are 0%, 0.01%, 0.02%, 0.03%, 0.04%, 0.05%, respectively. The results show that:(1) there exists an optimum ratio of wood fiber to colloidal silica, that is, as the concentration of wood fiber increases, the strength represented by the peak value of deviator stress rises first and then falls; (2) there are opposite trends between the two strength parameters, internal friction angle and cohesion, that is, when the wood fiber concentration is 0.04%, the cohesion reaches the maximum value and the internal friction angle reaches the minimum value; (3) The photos by SEM show that, there are wood fibers on the inner wall of the crack in the silica gel, which may reduce the extent of crack propagation and contribute to the strength of stabilized sand samples.

Keywords: calcareous sand, colloidal silica, wood fiber, tri-axial test

1 Introduction

Biological effects such as corals and seashells form marine calcareous sands which are widely distributed. Calcareous sands are used to make artificial islands in the ocean and serve as subgrades for shipping terminals. However, calcareous sands are easy to break, which are different from non-crushable silica sands. Therefore, the acoustic emission(AE) technique was used to detect the AE signals during the crush of calcareous sands[1]. Besides, strength characteristics obtained by tri-axial tests were compared between non-crushable silica soil and crushable calcareous soil[2]. Furthermore, Dynamic behaviors of calcareous sands were also obtained by dynamic tri-axial tests[3-5].

There are some newly developed methods to stabilize sand. For instance, microbial induced calcite precipitation (MICP) utilizes bacteria metabolic activities to produce insoluble $CaCO_3$ which bonds sand particles, and liquefaction resistance of MICP stabilized calcareous sand was studied by dynamic tri-axial tests [6]. Another stabilization method for loose sand is to use colloidal silica. Colloidal silica is non-toxic and can rapidly seep through loose sand since it has a low viscosity. There are stably suspended silica nano-particles in colloidal silica under an alkaline environment. By adjusting the pH of colloidal silica from alkaline to different acidic values, it takes different lengths of time for the silica nano-particles to gradually agglomerate to form a silica gel. Thus colloidal silica can be utilized to stabilize loose sand by seepage. The mechanism for colloidal silica transport in sand was studied [7-8]. Besides, different tests, such as full-scale explosion test [9], centrifuge tests [10-12] and tri-axial tests [13-17] were carried out to evaluate liquefaction mitigation of loose sand treated by colloidal silica.

However, for the silica gel bonding sand particles, a lot of micro-cracks in the gel can be seen from the photos by scanning electron microscope (SEM). Such micro-cracks reduce the strength of the silica-gel/sand composite. Therefore, in the hope that wood fiber would inhibit crack propagation in the gel, this paper attempts to disperse wood fiber in the colloidal silica, and inspects the microscopic mechanism and the reinforcement effect of wood fiber on calcareous sand seeped by colloidal silica.

2. Experimental materials and sample preparation

The calcareous sand is from the Philippines. The particle gradation curve of the sand sample is shown in Figure 1, and the properties of the calcareous sand are shown in Table 1.

The colloidal silica has a concentration of 20% by weight and is provided by Qingdao Maike Silica Gel Dessicant Co., Ltd. The silica nano-particles, which are suspended under an alkaline environment, are in the range of 1 to 100 nm.

The wood fiber is shown in Figure 2 and is provided by Shanghai Wuyuan Chemical Technology Co., Ltd. For the wood fiber, the length is below 1 mm, the pH is about 7.5, and the density is 1.3~1.5g/cm^3.

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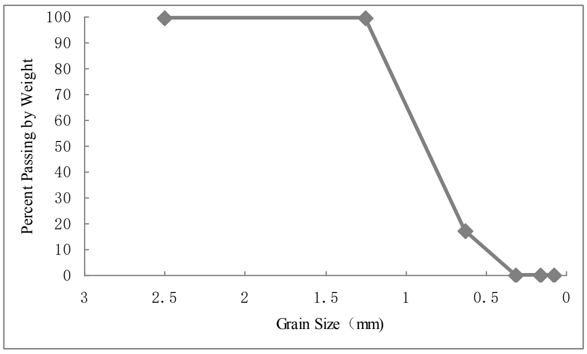


Fig. 1. Grain size distribution

Table 1. Properties of calcareous sand sample

Max. Voids Ratio (e_{max})	1.34
Min. Voids Ratio (e_{min})	1.03
Max. Dry Density	1370kg/m^3
Min. Dry Density	1190kg/m^3
Specific Gravity (G_s)	2.79
Coefficient of Uniformity (C_u)	1.9
Relative Density	0.516

Fig. 2. Wood fiber

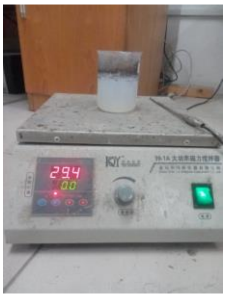


Fig. 3. Magnetic stirring

Fig. 4. Injection of colloidal silica into calcareous sand

The pH of colloidal silica was adjusted to 5~5.5 by dropping with acetic acid. Then the wood fiber and colloidal silica were mixed together, and this mixture was magnetically stirred for 60 minutes to uniformly disperse the wood fiber in the colloidal silica, as shown in Figure 3. Finally, by a peristaltic pump, the colloidal silica dispersed with wood fiber was injected into calcareous sand to form a reinforced cylindrical sample, as shown in Figure 4.

3. Testing scheme

In order to obtain the strength of stabilized sand, tri-axial tests are carried out by GDS advanced tri-axial system, as shown in Figure 5. The stabilized soil sample has a diameter of 39 mm and a height of 78 mm. The axil loading rate is 4mm per minute, and the experimental results were obtained from consolidated-undrained triaxial tests. The wood fiber concentrations and cell pressure settings are shown in Table 2.

Fig. 5. Sample prepared for tri-axial test

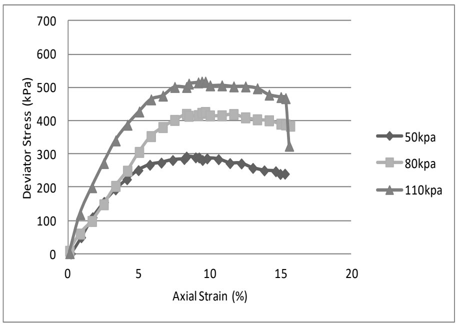
Table 2. Test parameters

Test number	Wood fiber concentration	Effective cell pressure (kPa)
1	0%	50
2	0%	80
3	0%	110
4	0.01%	50
5	0.01%	80
6	0.01%	110
7	0.02%	50
8	0.02%	80
9	0.02%	110
10	0.03%	50
11	0.03%	80
12	0.03%	110
13	0.04%	50
14	0.04%	80
15	0.04%	110
16	0.05%	50
17	0.05%	80
18	0.05%	110

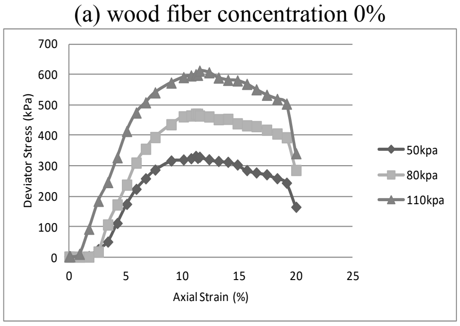
4. Results and discussion

A stabilized sample after tri-axial test is shown in Figure 6. Curves of the deviator stress versus axial strain for different wood fiber concentrations and cell pressures are shown in Figure 7. Curves of peak deviator stress versus wood fiber concentration under different cell pressures are shown in Figure 8, which demonstrates that the addition of wood fiber can enhance the strength of calcareous sand seeped by colloidal silica. But as wood fiber concentration increases, the peak value of deviator stress first rises and then falls, which suggests that there exists an optimum ratio of wood fiber to colloidal silica. That is, for cell pressures of 50 kPa and 110 kPa, the optimum concentration of wood fiber is 0.03%. A possible explanation is that, though wood fiber can inhibit the expansion of the microcracks in the silica gel bonding sand particles, excessive wood fiber increases the internal defects in the silica gel and causes a decrease in strength.

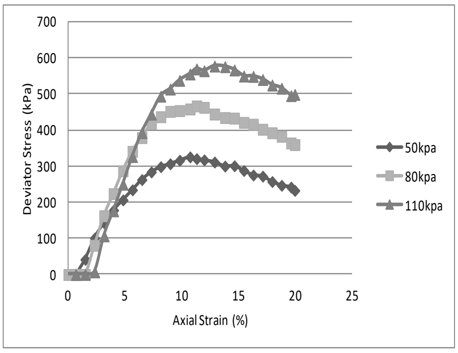
Fig. 6. Sample after tri-axial test (wood fiber concentration 0.03%)



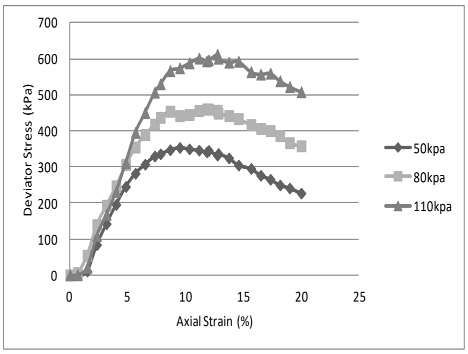
(a) wood fiber concentration 0%



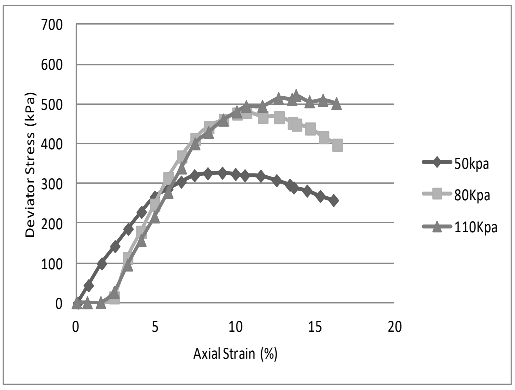
(b) wood fiber concentration 0.01%



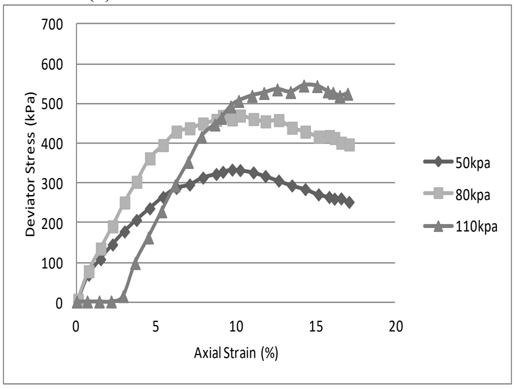
(c) wood fiber concentration 0.02%



(d) wood fiber concentration 0.03%



(e) wood fiber concentration 0.04%



(f) wood fiber concentration 0.05%

Fig. 7. Deviator stress versus axial strain

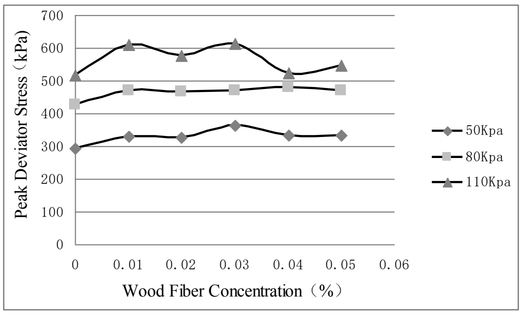


Fig. 8. Peak deviator stress versus wood fiber concentration

The internal friction angle and cohesion of stabilized samples under different wood fiber concentrations are shown in Table 3. The curves of internal friction angle and cohesion versus wood fiber concentration are shown in Figure 9 and Figure 10, respectively. Internal friction angle decreases first and then increases as the wood fiber concentration increases, i.e., reaches its minimum value at the fiber concentration of 0.04%. Conversely, as the wood fiber concentration increases, cohesion increases first and then decreases, i.e., reaches its maximum value at a fiber concentration of 0.04%.

Table 3. Cohesion and angle of internal friction

Wood fiber concentration (%)	Angle of internal friction (°)	Cohesion (kPa)
0	40.8	24.8
0.01%	44.4	20.4
0.02%	42.7	26.4
0.03%	42.5	32.4
0.04%	38.9	41.5
0.05%	39.9	37.9

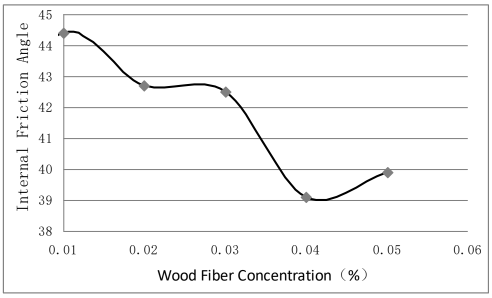


Fig. 9. Angle of internal friction versus wood fiber concentration

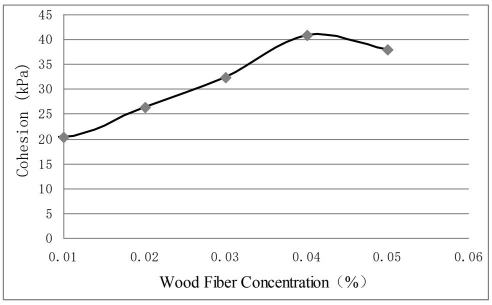
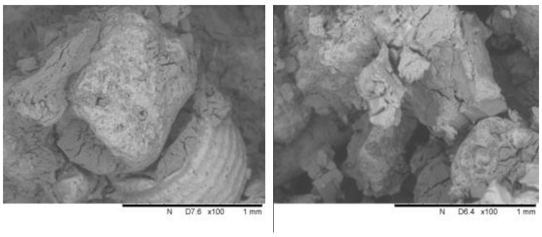
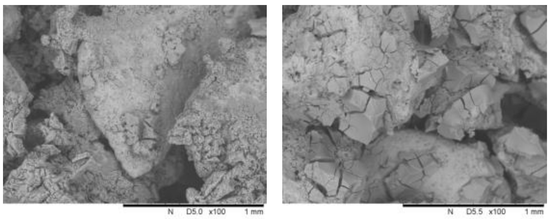


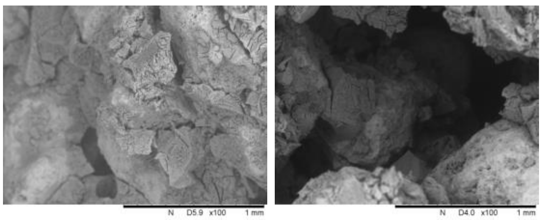
Fig. 10. Cohesion versus wood fiber concentration



(a) 0% wood fiber (b) 0.01% wood fiber



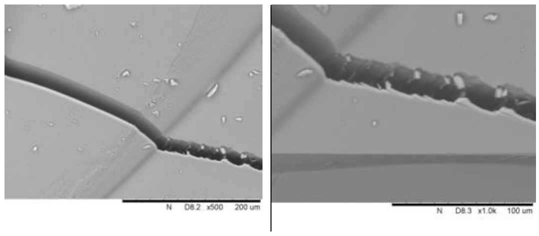
(c) 0.02% wood fiber (d) 0.03% wood fiber



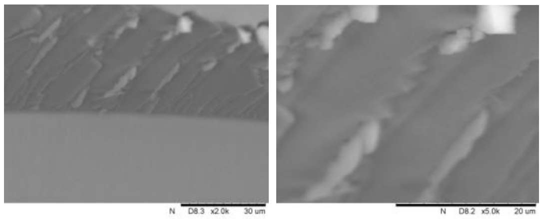
(e) 0.04% wood fiber (e) 0.05% wood fiber

Fig. 11. SEM photos of gel-sand composite under different wood fiber concentrations

Figure 11 shows SEM photos of calcareous sand particles cemented by silica gel at different wood fiber concentrations. Micro-cracks in the gel can be clearly observed especially from Figure 11(d). It is difficult to photograph the wood fibers in the silica gel when mixing sand particles. Therefore, without calcareous sand, by utilizing silica gel formed by colloidal silica which is dispersed with wood fibers at the concentration of 0.05%, wood fibers on the inner wall of the micro-crack in the gel are photographed by SEM, as shown in Figure 12. From photos by SEM, the inner wall of the micro-crack is interspersed with wood fibers, which may play a role in reducing crack propagation.



(a) Zoom in 500 times (b) Zoom in1000 times



(c) Zoom in 2000 times (d) Zoom in 5000 times

Fig. 12. Different magnifications of wood fibers on the inner wall of the same crack in the silica gel

5. Conclusion

In this study, a series of tri-axial tests have been taken to investigate the effect of wood fiber on the strength of calcareous sand seeped by colloidal silica. Besides, wood fibers interspersed on the wall of the micro-crack in silica gel are photographed by SEM. The following findings can be drawn from this work:

(1) There exists an optimum wood fiber concentration to strengthen calcareous sand. For stabilized sand under most cell pressures, colloidal silica dispersed by 0.03% wood fiber can obtain the greatest strength. Obviously, excessive wood fiber concentration leads to a decrease in strength. A possible explanation is that excessive fibers increase defects in the gel and weaken the strength.

(2) Cohesion and internal friction angle show opposite trends as the wood fiber increases. At the fiber concentration of 0.04%, cohesion reaches its maximum value and internal friction angle reaches its minimum value.

(3) The SEM photos show wood fibers intersperse around the micro-crack in the silica gel. These wood fibers may contribute to the inhibition of crack propagation and enhance the strength of stabilized calcareous sand.

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