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Experimental Study and Mechanism Analysis of the Mechanical Property of Cement Soil with Different Straws

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Through the measure of adding untreated wheat straw or rice straw to cement soil, the paper proposed a fundamental concept of cement soil with straw. From the perspectives of straw length, reinforcement ratio, straw shape, age of cement soil, and cement mixing ratio, the paper compared and analyzed both the unconfined compressive strength and the flexural strength between cement soil with wheat straw and cement soil with rice straw. The result shows that the strength of cement soil with wheat straw surpasses that of cement soil with rice straw. As straw length increases, the unconfined compressive strength of both the two kinds of cement soil tends to decrease in general; under the same circumstance, the flexural strength increases constantly for the cement soil with wheat straw, while decreases first and then increases for the cement soil with rice straw. As reinforcement ratio rises, the unconfined compressive strength of the cement soil with wheat straw edges down gradually, while the unconfined compressive strength of the cement soil with rice straw peaks at 0.2% of the reinforcement ratio; on the same condition, the flexural strength of both the two kinds of cement soil tends to decrease by and large. In terms of rice straw shape, rice straw in full circle tops the impact on the compressive strength of cement soil, followed by rice straw in semi-circle; and quadrant rice straw exerts the minimum influence on the compressive strength of cement soil. In contrast, wheat straw shape has a negligible effect on the compressive strength of cement soil. Neither age of cement soil nor cement mixing ratio has extra effect on cement soil with straws than on ordinary cement soil. Finally, the function mechanism of straw in cement soil was analyzed briefly in the paper.

1. Introduction

Cement soil is a mix of pulverized natural soil with certain amount of Portland cement. Characterized by low cost and little environmental pollution, cement soil is widely applied to foundation treatment and supporting structures of foundation pit. Meanwhile, it also has disadvantages, such as low flexural strength and poor crack resistance (LU et al., 2009; Anagnostopoulos, 2015). Therefore, it is particularly necessary to improve mechanical performance of cement soil to a degree that satisfies engineering requirements. In this connection, the most commonly-used approach is to mix cement soil with fibrous material, including polypropylene fiber, glass fiber, and steel fiber, aiming to enhance cement soil strength. Currently, corresponding research has been undertaken extensively at home and abroad. For example, Yin Y used triaxial tests to study the impact of different contents of glass fiber on shear properties of cement soil with glass fiber (YIN and YU, 2011). Tang C.S. conducted research on how initial water content of weak soil, fiber content, and fiber length impact on the strength of reinforced cement soil with fiber (TANG and GU, 2011). By controlling cement content, porosity and other parameters, Consoli studied the tensile strength and compressive strength of cement soil with fiber (Consoli et al., 2013). Liu J.Z. applied glass fiber grids to cement soil, and studied strength and stability of cement soil through laboratory tests and full-scale experiments (LIU et al., 2014). In the light of flexural behaviour improvement, by adding steel fiber and polypropylene fiber into cement soil piles, Sukontasukkul concluded that cement soil with polypropylene fiber is more resilient than cement soil with steel fiber (Sukontasukkul and Jamsawang, 2015). Martins mixed coal ashes, metakaolin, and plant fiber with self-compacting cement soil, with the intention of enhancing the maximum strength and toughness of cement soil (Martins et al., 2015). By adding rice chaff ash to cement soil with polypropylene fiber, Kumar studied the impact of rice chaff ash contents on cement soil strength (Kumar and Gupta, 2016).

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As a natural fibrous material, when being added to cement soil, straw helps improve mechanical performance of cement soil. However, on account that straw tends to corrode or even decay in environments as damp as cement soil, it is difficult for cement soil with straws to be applied to permanent engineering such as foundation consolidation and slope reinforcement. The temporality of supporting structures of deep foundation pit allows cement soil with straws to serve supporting structures of cement soil mixing piles, on the premise that the straw is sure to maintain certain reinforcement effect in a relatively short time when its strength does not diminish due to corrosion. Therefore, it is possible that natural straw is employed to supporting structures of cement soil mixing piles.

As two kinds of common straw, rice straw and wheat straw both have certain tensile properties. Cement soil with straws has better strength than cement soil, but with poorer strength or non-deformability than synthetic fibrous materials. Therefore, it is necessary to know the mechanical performance of and the different between cement soil with rice straw and cement soil with wheat straw, to the advantage of engineering application of both of them.

From the perspectives of straw length, reinforcement ratio, straw shape, age of cement soil, and cement mixing ratio, the paper compares both the unconfined compressive strength and the flexural strength between cement soil with wheat straw and cement soil with rice straw. The analysis of their strength acts as a preliminary exploration of cement soil with straws.

2. Experiment Scheme

2.1 Experiment materials

Mucky silty clay, which was taken from soil at the 5m depth of a foundation pit in Yancheng city, Jiangsu province, was used in the experiment. The unit weightγ=18.3 KN/m3, water content w=33.5%, porosity e=0.52, plasticity index Ip=13.5, and compressive coefficient a=0.55MPa-1. The cement in the test was P.O.42.5 ordinary Portland cement from Jiangsu Baling Conch Cement Company limited, whose properties conformed to specification requirements. Table 1 shows indices of the physical property of P.O.42.5 ordinary Portland cement.

Table 1: Indices of the physical property of P.O.42.5 ordinary Portland cement

Fineness /%	Initial setting time/min	Final setting time/min	Stability	Loss on ignition /%	Compressive strength/MPa		Flexural strength/MPa	
					3d	28d	3d	28d
3.8	125	180	passed	2.1	26.3	54.2	5.1	8.2

The rice straw and wheat straw, both of which came from rural fields in Yancheng city, were stripped before the test, and no fractured straw were used. Through certain tests of 10 joint-free 10-centimeter-long rice straw and 10 joint-free 10-centimeter-long wheat straws, the uplift capacity of them was obtained as 106.2N and 114.7N, respectively.

2.2 Experiment methods

From the perspectives of straw length, reinforcement ratio, straw shape, age of cement soil, and cement mixing ratio, the paper compared and analyzed both the unconfined compressive strength and the flexural strength between cement soil with wheat straw and cement soil with rice straw. Table 2 shows working conditions of the experiment.

The size of samples for the unconfined compressive strength test was 70.7mm×70.7mm×70.7mm, and 40mm×40mm×160mm for the flexural strength test. During sample preparation, the molds were assembled before oiling their inner walls evenly. Then, the molds were filled with straw-cement mixture in a layered manner, and the mixture was compressed and pressed until the mold space was completed filled. When the mold surface was flattened out manually, the molds were covered with plastic films. After 24h's standing, samples were taken out of the molds, numbered, and soaked in water. Next, the samples were fetched from the water, and enclosed with wet towels for fear of water loss 24 hours before the set age arrived. Afterwards, the cement soil samples underwent the unconfined compressive strength test and the flexural strength test, respectively (both of them were parallel tests concerning three specimens). Finally, the unconfined compressive strength and the flexural strength of cement soil specimens under different working conditions were determined through computation.

Table 2: Working conditions of the experiment

No.	Influential factors	Constant factors
1	Age (7d, 14d, 21d, 28d)	straw length(10mm), reinforcement ratio (0.2%), straw shape (semi-circle), cement mixing ratio (15%)
2	cement mixing ratio (5%, 10%, 15%, 20%)	age(28d), straw length(10mm), reinforcement ratio (0.2%), straw shape (semi-circle)
3	straw length (5mm, 10mm, 15mm, 20mm, 25mm)	age(28d), reinforcement ratio (0.2%), straw shape (semi-circle), cement mixing ratio (15%)
4	reinforcement ratio (0.1%, 0.2%, 0.3%, 0.4%, 0.5%)	age(28d), straw length(10mm), straw shape (semi-circle), cement mixing ratio (15%)
5	straw shape (full circle, semi-circle, and quadrant)	age(28d), straw length(10mm), reinforcement ratio (0.2%), cement mixing ratio (15%)

3. Experimental results and analysis

3.1 Influence of straw length

Figure 1 is the curve of the relations between the strength of cement soil with straws and straw length. As could be seen, either the unconfined compressive strength or the flexural strength of cement soil with wheat straw surpassed that of cement soil with rice straw. As straw length increased, the unconfined compressive strength of cement soil with straws underwent gradual descent in general. This phenomenon proved that the mixing of longer straw rendered cement soil less compacted. The reason was that the uncompacted straw was inclined to cause long cracks that connected promptly to fragile parts in the cement soil, and it was the connection that undermined cement soil and further reduced the strength. When the straw was 20mm long and 15mm long, there appeared rebound for the unconfined compressive strength of cement soil with rice straw and that of cement soil with wheat straw.

The flexural strength of cement soil with wheat straw tended to rise gradually as a result of the reinforcement effect of wheat straw. By contrast, the flexural strength of cement soil with rice straw decreased first, hitting the bottom when the straw was 20mm long, and increased later as the reinforcement effect of rice straw started to work.

Therefore, wheat straw was preferable to rice straw as the mixing substance for cement soil. What's more, the mix of straw of suitable length would help cement soil increase flexural strength at the same time when the unconfined compressive strength of the mixture escape from overmuch reduction. In other words, the reinforcement effect of wheat straw could come into play.

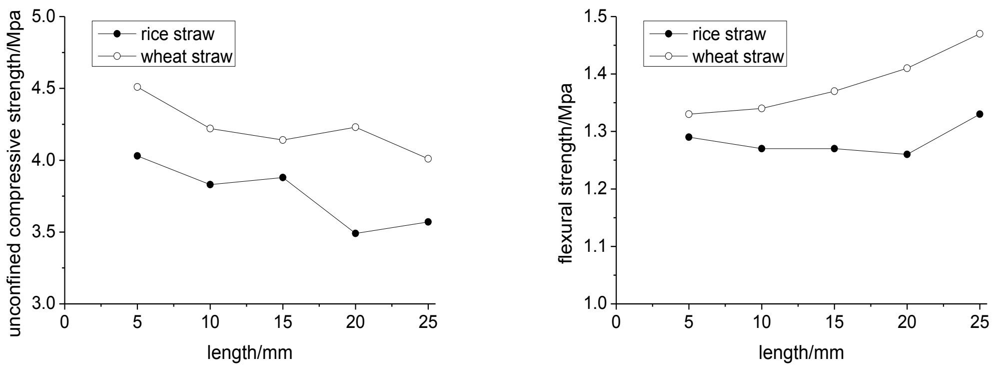

Figure 1: The curve of the relations between the strength of cement soil with straws and straw length

3.2 Influence of reinforcement ratio

Figure 2 is the curve of the relations between the strength of cement soil with straws and reinforcement ratio. As could be seen, for cement soil with wheat straw, with the increase of reinforcement ratio, the unconfined compressive strength dropped gradually. In contrast, for cement soil with rice straw, when the reinforcement ratio rose from 0.1% to 0.2%, the unconfined compressive strength increased slightly; as the reinforcement ratio continued to climb, the unconfined compressive strength tumbled first and then saw a small advance. With regards to flexural strength, the changing inclination of cement soil with rice straw agreed with that of cement soil with wheat straw. The flexural strength earned a gain when the reinforcement ratio reached 0.3%, but then decreased continuously. This is because the high reinforcement ratio or overmuch straw renders it difficult for the cement soil with straws to be mixed evenly, under whose circumstance the straw in the cement

soil with straws takes on the fascicle-like structure that will be destroyed under the influence of external load. Moreover, too much straw tends to diminish the compact structure of cement soil. As a result, there appear pores between straw and cement soil, which lowers the completeness of gelatinous substances in cement soil, and affects cement soil strength as well. Once external pressure is exerted on cement soil with straws, the growth of cracks accelerates into connecting fractures, thus reducing the strength of cement soil with straws.
Thus, when the reinforcement ratio is low, the strength of either cement soil with rice straw or cement soil with wheat straw can remain intact and even increase slightly. If conditions permit, or if proper improvement is done on straw, it will be feasible for cement soil with straws of low reinforcement ratio to be put into practical engineering application.

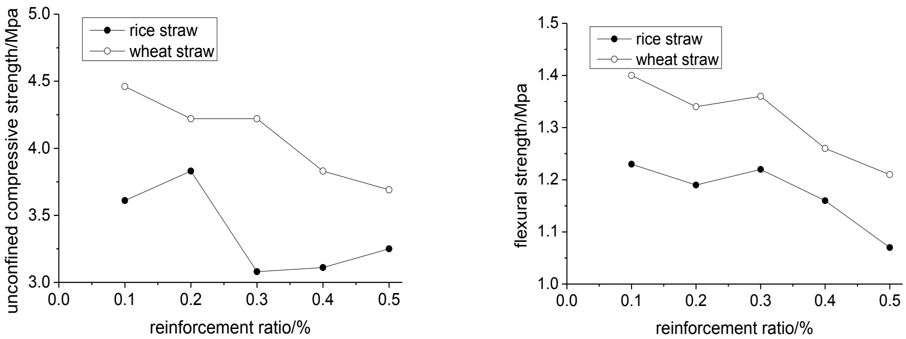

Figure 2: The curve of the relations between the strength of cement soil with straws and reinforcement ratio

3.3 Influence of straw shape

Cement soil with rice & wheat straw of full-circle section, semi-circle section, and quadrant section is prepared, respectively, aiming to study the tensile strength of rice straw and wheat straw in cement soil. Table 3 is the strength of cement soil with different straw shapes. As could be seen, the influence of straw shape on the unconfined compressive strength of cement soil with wheat straw was negligible, while straw shape had certain effect on the unconfined compressive strength of cement soil with rice straw. Specifically, compared to the strength of cement soil with semi-circle rice straw, the strength of cement soil with full-circle rice straw increased by 4.2%, while the strength of cement soil with quadrant rice straw decreased by 6.0%. The reason is that the inner section of the rice straw is rougher than the outer section. Once the rice straw is sectioned, there is more contact between cement soil and the inner straw section, which lowers the occlusal force and the binding power. By contrast, wheat straw has the inner section as rough as the outer section. The straw shape exerts little influence on the flexural strength of the cement soil with straws. The flexural strength of cement soil with full-circle rice straw is minimums. The maximum flexural strength appears in cement soil with quadrant wheat straw, with a gain of 3.8% and 2.4% in comparison with the flexural strength of cement soil with full-circle rice straw and that of cement soil with full-circle wheat straw, respectively. Therefore, the impact of straw shape on the flexural strength of cement soil with straws can be ignored.
All in all, the one with full-circle section is recommendable while the rice straw is selected. There is no difference among wheat straw with full-circle section, wheat straw with semi-circle section, and wheat straw with quadrant section to be mixed with cement soil, but wheat straw with full-circle section takes priority with respect to applicability and accessibility.

Table 3: The strength of cement soil with different straw shapes

Strength	Type of straw	Straw section		
		Full-circle	Semi-circle	Quadrant
Unconfined compressive strength/Mpa	Wheat straw	4.24	4.22	4.23
	Rice straw	3.98	3.83	3.60
Flexural strength/Mpa	Wheat straw	1.30	1.34	1.35
	Rice straw	1.25	1.27	1.28

3.4 Influence of age and cement mixing ratio

Figure 3 is the relation between the strength of cement soil with straws and age. As could be seen, either the unconfined compressive strength or the flexural strength of cement soil with straws increased with the increase of age. Meanwhile, as the cement mixing ratio rose, the strength of cement soil with straws gradually climbed up, as shown in Figure 4. Similarly, the strength of cement soil with wheat straw surpassed that of cement soil with rice straw.

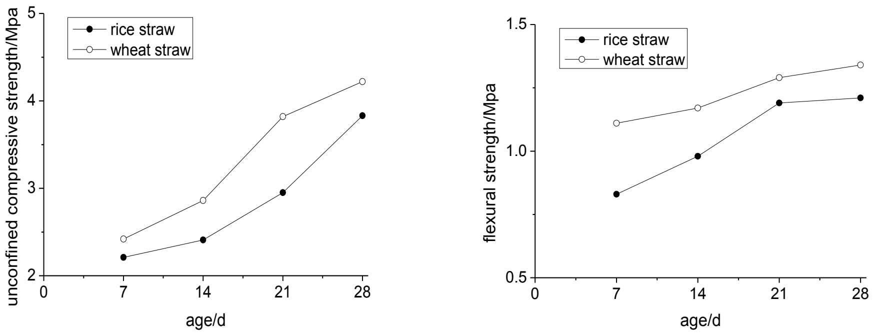

Figure 3: The curve of the relations between the strength of cement soil with straws and age

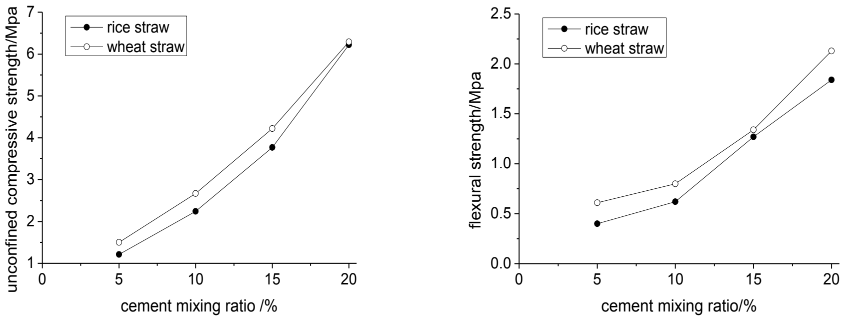

Figure 4: The curve of the relations between the strength of cement soil with straws and cement mixing ratio

4. Analysis of the function mechanism of cement soil with straws

4.1 Chemical action of cement soil

Soil mass is a mix of soil particles with different grain compositions, whose strength is mainly determined by the cohesive power and friction between soil particles. When a certain amount of cement is added to clay, surface minerals of cement particles hydrolyze and hydrate with water promptly, resulting in the generation of calcium hydroxide, hydrous calcium silicate, and hydrous calcium ferrite. At the same time, a series of chemical reaction occurs among cement, high-content silicon dioxide, and high-content alumina, producing massive hydration products and gelatinous substances such that the soil particles are closely bonded into granular structure. In addition, the reciprocal interchange between various charged ions of cement and adsorbed ions of soil particles helps soil particles to be bonded and granulated together, enhancing the strength and stability of cement soil. The major source of cement soil strength is the gelatinous substances derived from hydrolysis reaction and hydration reaction.

4.2 Analysis of the role of straw in cement soil

Since the ancient time, straw (mostly wheat straw) has been mixed with clay in order to enhance the clay strength in China. The same principle applies to the measure of adding straw to cement soil. The even mix of cement soil with straws will produce certain binding power between them along with the condensation of cement soil. Given that under the influence of external load, there appear cracks in fragile parts of cement soil, the existence of straw will prevent cracks from amplification. Meanwhile, as cement soil hardens, the occlusal force and binding power of the contact surface between straw and cement soil are intensified, thus increasing the strength and stability of cement soil.

However, considering the existence of alkali-aggregate reaction in the cement soil with straws and that the straw lacks compactness, the measure of adding straw to cement soil often lowers the strength. Nevertheless, according to the results of the above tests, the mix of straw of suitable length would help increase cement soil strength on the premise of low reinforcement ratio. It should be noted that the untreated straw will inevitably decay or corrode in humid environments for long enough. Still and all, as long as it plays a role over a short period of time (2-4 months, for example), straw can act as an addition to cement soil that is used in supporting structures of foundation pit for mixing piles, because the supporting structures are temporary.

5. Conclusions

The paper applied rice straw and wheat straw separately to cement soil, and compared the unconfined strength and flexural strength of cement soil with rice straw and wheat straw. The result shows that the strength of cement soil with rice straw surpasses that of cement soil with wheat straw. What's more, the function mechanism of cement soil with straws was analyzed in the paper for the following conclusions:

(1) As straw length increased, the unconfined compressive strength of cement soil with straws underwent gradual descent in general. The flexural strength of cement soil with wheat straw tended to rise gradually. By contrast, the flexural strength of cement soil with rice straw decreased first and increased later.

(2) For cement soil with wheat straw, with the increase of reinforcement ratio, the unconfined compressive strength dropped gradually. In contrast, for cement soil with rice straw, when the reinforcement ratio amounted to 0.2%, the unconfined compressive strength hit the peak. The flexural strength of either cement soil with rice straw or wheat straw decreased constantly in general, except for a gain when reinforcement ratio was 0.3%.

(3) The straw shape exerts certain influence on the unconfined compressive strength of the cement soil with rice straw. Specifically, rice straw in full circle tops the impact on the compressive strength of cement soil, followed by rice straw in semi-circle; and quadrant rice straw exerts the minimum influence on the compressive strength of cement soil. However, rice straw shape has little effect on flexural strength. As a comparison, wheat straw shape has a negligible effect on either the unconfined compressive strength or the flexural strength of cement soil.

(4) As with ordinary cement soil, either unconfined compressive strength or flexural strength of cement soil with straws increased with the increase of age. The same phenomenon appeared on cement mixing ratio.

The comparison between strength of cement soil with rice straw and that of cement soil with wheat straw is preliminary in the paper. Numerous trials and studies are needed before cement soil with rice straw or cement soil with wheat straw is applied to practical engineering, such as further analysis of the reinforcement effect of straw in cement soil and the micro mechanism of the strength of cement-soil mixture. Such analysis will help stretch the potential of cement soil with straws to the maximum, but with technological difficulty at the same time. In this regard, further research is needed.

Acknowledgments

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