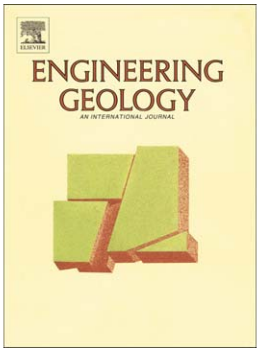

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PII: S0013-7952(14)00121-5
DOI: doi: 10.1016/j.enggeo.2014.05.013
Reference: ENGEO 3794

To appear in: *Engineering Geology*

Received date: 18 July 2013
Revised date: 17 February 2014
Accepted date: 7 May 2014

Please cite this article as: Qiang, Xue, Hai-jun, Lu, Zhen-ze, Li, Lei, Liu, Cracking, water permeability and deformation of compacted clay liners improved by straw fiber, *Engineering Geology* (2014), doi: 10.1016/j.enggeo.2014.05.013

Cracking, water permeability and deformation of compacted clay liners improved by straw fiber

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Abstract: The cracking resistance performance, impermeability, strength and deformation characteristics of an improved clay were systematically evaluated by cracking test, water permeability test, unconfined compression test and shear test, respectively. The cracking test suggested a high resistance of the improved clay by straw fiber against cracking. With the increase of fiber content (FC), the cracking intensity factor (CIF) i.e. the ratio of the crack area to the total area, decreased at low fiber contents and then turned to increase at higher fiber contents. However, the effect of fiber additive on the surface shrinkage was not significant. The improved clay with FC=0.3% was found to have the highest resistance to cracking. After 25 days of desiccation, CIF and surface shrinkage of compacted clay were determined to be 0.015 and 12.1% respectively. However, CIF of the improved clay with FC=0.3% was only 0.0013 and surface shrinkage was 10.31%. Cracking was propagated by wetting-drying cycles. After four wetting-drying cycles, the CIF of the compacted clay was 0.032 and the CIF of the improved clay with FC=0.3% was 0.0081. The result of water permeability test for cracked clay indicated that a traditional landfill cover system merely consisting of compacted clay would not be sufficient to serve as an effective barrier against rainwater permeation into the landfill. At a rainfall intensity of 10mm/d, the rainwater penetrated to a 15 cm depth of the clay liners. The improved clay with FC=0.3% had the least permeability. The rainwater had not penetrated to the 15cm depth of clay liners even if the rainfall intensity reached 50mm/d. The results of unconfined compression tests and shear tests indicated that with the increase of FC, the unconfined compressive strength and shear strength increased firstly and then decreased. At FC=0.3%, the unconfined compressive strength peaked at 459.15kPa, and c, φ peaked at 80.9kPa and 21.06°, respectively. The improved clay with straw fiber additive could be used in landfill cover system to enhance the anti-seepage ability and strength of landfill liners.

Key words: landfill cover system, straw fiber, improved clay, desiccation cracking, cracking intensity factor

1. Introduction

In order to reduce the leachates from municipal solid waste (MSW) and protect the ecological environment safety, the landfill cover system is required to be constructed when the storage limit is achieved. The compacted clay cover structure is recommended by “Technical code for municipal solid waste sanitary landfill” (CJJ17-2004), and the hydraulic conductivity of compacted clay must be less than 1×10^{-7}cm/s. However, desiccation cracking of the landfill cover system with compacted clay can occur under the action of both external and internal circumstances (Tang et al., 2010; Li and Zhang, 2011). Once the landfill cover system cracks, it would provide convenient flow path for the rainwater and thus increase the amount of leachate from MSW in landfill. Albrecht and Benson showed that desiccation cracking caused the hydraulic conductivity of clay liner to increase by about three orders of magnitude（Albrecht and Benson, 2001）.

A number of research efforts have been made to overcome the problems of desiccation cracking in landfill cover system. A few have considered soil additives (lime, sand, and cement) to increase the soil strength and resistance to cracking (Leung and Vipulanandan, 1995; Omidi et al., 1996a, b; Cetin et al., 2006). However, the effect of addictives to constrain cracking was not significant and the required low permeability in landfill cover system was not achieved. In recent years, due to good toughness and ductility in fiber material, it was widely used in compacted clay and concrete to improve the shear strength and resistance to cracking. In recent decades, the engineering characteristics of soil containing fibers have been studied with triaxial tests, unconfined compression tests, direct shear tests, CBR tests and permeability tests. Polypropylene fiber is a common synthetic material that is widely used to reinforce soil and concrete (Maher and Ho, 1994; Nataraj and McManis, 1997; Cetin et al., 2006; Tang et al., 2007; Ozkul et al., 2007; Harianto et al., 2008). In addition, other materials were used as the additives improving the strength and resistance to cracking of compacted clay. The effects of length and content of sisal fibers on the clay strength were studied by Prabakar and Sridhar (Prabakar and Sridhar, 2002). Physical property and reinforcement effects of coconut fibers were studied experimentally by Khosrow et al（Khosrow et al., 1999）. Silica fume and red mud were proposed as the modifiers for compacted clay to improve the strength and resistance to cracking (Kalkan and Akbulut, 2004; Kalkan, 2006; Kalkan, 2009).

In China, most of straw is burned in rural area as a traditional fuel, which has led to a waste of resource and environmental pollution. The straw fiber can be extracted from straw and used as a soil additive to form a straw fiber-clay mixture, which can avoid ecological environment pollution induced by burning straw and improve resistance of landfill cover system to cracking. Thermogravimetric analysis and thermomechanical analysis were applied by Zabihzadeh to study the thermal stability and thermal expansion of mixture of wheat straw powder, polypropylene and high density polyethylene (Zabihzadeh, 2010). Pradhan et al. has observed physicochemical properties of biological treated soybean-straw fiber (Pradhan et al., 2009). Wheat straw was used by

Bolcu and Stanescu to reinforce epoxy resin. Bolcu and Stanescu determined the elastic modules and tensile strength of the mixture through laboratory tests (Bolcu and Stanescu, 2010). Xue et al. successfully extracted straw fiber from straw wastes for application in road construction and characterized its surface microstructure and mechanical property (Xue et al., 2009).

In this paper, straw fiber was used as reinforcement additive to improve the compacted clay strength and resistance to cracking. To evaluate the feasibility of fiber-clay mixture as the material of landfill cover system, cracking test was applied for the improved clay in the conditions of dehydration and multiple wetting-drying cycles to determine the resistance of fiber-clay mixture to cracking. The permeability of cracked clay in the condition of rainfall was studied by water seepage tests. The permeability of straw fiber-improved clay was tested with the PN3230M environmental soil flexible wall permeameter under dry-wet cycles. Strength and deformation characteristics of fiber-clay mixture were analyzed by unconfined compression tests and direct shear tests.

2 Materials and test methods

2.1 Materials

The clay used in this study was taken from an excavation site in Changqing Garden in Wuhan. The soil samples were collected on the site at 5~7 m deep underground. The chemical composition and fundamental physical indexes are listed in Table 1 and Table 2, respectively.

The straw fiber was extracted by alkaline soaking. The impurities, such as leaf, ear, joint, were removed from straw. The raw straw with length of 3~5cm was cleaned, dried and then packed. The dosage of NaOH to raw straw was 10%. The straw sample was cooked under the temperature of 150~160℃ and at the maximum pressure of 380~530kPa for 3~4h. The high temperature digester was used in the preparation. The straw fiber was extracted though cooking, filtration, washing, and drying. The chemical composition of straw is presented in Table 3 and the fundamental physical properties of straw fiber are listed in Table 4. The microstructure of straw fiber is shown in Fig.1. The straw fiber surface appears rough and uneven with visible grooves, as shown in Fig.1.

2.2 Test methods

Different straw fiber contents (0、0.05%、0.1%、0.2%、0.3%、0.4%、0.5%) were used for the preparation of compacted clay at a given target dry density (1.65g/cm^3) and initial moisture content (0.19). These soil samples were further subject to cracking test under the impacts of continuous dehydration and wetting-drying cycles. The cracking test was conducted in oven at a stable temperature of 40℃. Electronic balance was used to determine the change of moisture content in compacted clay. A digital microscopic image system was applied to monitor the development of cracks in compacted clay (Fig. 2). The clay samples were dried for 5 days followed by the first wetting-drying cycle, and then one cycle was conducted every 5 days. Four wetting-drying cycles were conducted in 25 days.

Water seepage test was conducted for the cracked clay under the action of four wetting-drying cycles. As shown in Fig. 3, the inner diameter of container is 50cm and the thickness of compacted clay is 20cm. For the soil samples, the compactness, moisture content and straw fiber content were at 1.65g/cm^3, 0.19 and 0.3%, respectively. Heating source and rainfall simulator could simulate the sun radiation and rainfall to form the wetting-drying cycles while lasting for 25 days. The 3 cm thick rubber blanket was laid on the inner-wall of container to prevent water from flowing along the container wall, which guaranteed seepage performance of cracked clay could be evaluated correctly. The moisture sensors were installed on the site at 5 cm, 10 cm and 20 cm depth from surface of soil layer, monitoring the changes of moisture contents of soil layer at different depth with elapsed time. The percolation behavior of the cracked clay was evaluated with rainfall intensities of 10mm/d and 50mm/d, respectively. The 1 hour-long rainfall was conducted by a rainfall simulator.

The PN3230M environmental soil flexible wall permeameter, made by American GEOEQUIP, was used to test the permeability of the straw fiber-improved clay under dry-wet cycles. The permeameter can prevent the sidewall leakage that might be caused by the specimen's volume change during the dry-wet cycles. The specimens used in this test have an initial dry density of 1.65 g/cm^3 and an initial moisture content of 19%. The straw fiber volume ratios used to improve clays were 0, 0.3%, 0.5%. The specimen was initially sized at a diameter of 50 mm and a height of 50 mm for permeability test. All samples were made by pressed a specific quantity soil into the cutting ring of the above-mentioned size. The samples were placed in a Vacuum Saturator can for 48h before permeability test, and then placed in a dryer for 72 h at 50 °C after permeability. The aforementioned steps were repeated for 4 dry-wet cycles.

Different straw fiber contents (0, 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%) were used in the preparation of compacted sample at a given target dry density (1.65g/cm^3) and initial moisture content (0.19) in unconfined compression tests and shear tests applied according to "Specification of soil test" (SL237-1999). YYW-2 Strain Controlled Unconfined Compression Apparatus with revolving speed of 60r/min (Nanjing soil instrument factory) was used to determine the unconfined compressive strength of improved clay cylinder sample with diameter of 40mm and height of 80mm. ZJ Strain controlled Direct Shear Apparatus with revolving speed of 4r/min (Nanjing soil instrument factory) was used to determine the shear strength of soil cylinder sample with diameter of 61.8mm and height of 20mm.

3 Results and discussions

3.1 Cracking of clay improved by straw fiber

3.1.1 Cracking of improved clay by straw fiber under drying condition

Cracking performance of compacted clay could be characterized by the cracking intensity factor

(CIF) which is the ratio of the crack area and the total area (Miller et al., 1998; Yesiller et al., 2000). The color of cracked area was dimmer than that of uncracked area. Thus, the digital microscopic image analysis software can be used to calculate CIF by the difference of colors of the crack area and the intact area.

The development of cracks in the compacted clay and clay-fiber mixed soil under continuous desiccation and dehydration was shown in Fig. 4. The cracks were observed on the surface of the compacted clay without fiber additive after 25 days of dehydration. Most of the cracks distributed on the periphery of soil samples while granule forms around the cracks , which was tensional failure caused by the lack of effective lateral confining stress relative to the pore water pressure under severe dehydration state. The drying shrinkage of compacted clay would lead to irreversible structural change, resulting in the failure of cohesive force between soil particles and the reduction in strength.

For compacted clay-fiber mixed soil, there appears to be no crack observed on the surface of samples even if the fiber content (FC) was as low as 0.05%,indicating that straw fiber improved the tensile strength in terms of soil. The microstructure of the compacted clay-fiber mixture (Fig. 5) showed that the connection and friction between soil particles and fibers had been improved. The horizontal tension force between soil particles developed due to the shrinkage in the process of dehydration. For compacted clay-fiber mixture, the horizontal tensile strength had been improved by straw fiber as well as friction between soil particles and fibers, which increased the resistance of the clay to cracking (Harianto et al., 2008).

The changes of surface shrinkage and CIF with moisture contents were shown in Fig. 6 and Fig. 7. For the compacted clay, the surface shrinkage and CIF were 12.1% and 0.015, respectively. For the compacted clay-fiber mixture, the surface shrinkage and CIF decreased to the minimum of

10.31% and 0.0013, respectively at FC=0.3%, showing a limited impact of straw fiber on the decrease of surface shrinkage. However, the straw fiber had a significant effect on CIF. For the compacted clay-fiber mixture, CIF almost decreased by 90% which indicated that the straw fiber could effectively restrain the development of cracks in mixed soil.

3.1.2 Cracking of improved clay by straw fiber under the action of wetting-drying cycles

The evolution of cracks of compacted clay improved by straw fiber under four wetting-drying cycles is shown in Fig. 8. The results showed that the wetting-drying cycles, relative to continuous dehydration, had a greater impact on the growth of cracks. More cracks developed on the surface of compacted clay, indicating that the wetting-drying cycles significantly influenced the structure of soil particles and incurred the lost of cohesive attraction between soil particles. Therefore the soil was shattered, which resulted in the development of cracks. Relative to the raw compacted clay, crack development of clay-fiber mixture was lower in velocity, indicating a higher resistance to cracking. The compacted clay without fiber additive (FC=0.0) cracked significantly and the cracks were crisscrossed. Some cracks had gone through the 2cm thick compacted clay sample, which provided flow path for water permeation and thus resulted in the rapid loss of anti-seepage ability of landfill cover system. Only little and shallow cracks existed on the surface of compacted clay-fiber mixture at FC=0.3% and thus had little influence on its permeability. Compacted clay-fiber mixture with FC=0.5% developed more surface cracks than the sample with FC=0.3%, but still remained to be less than the raw sample without fiber additive. Therefore, when FC reached 0.3%, the improved compacted clay could provide maximum resistance against cracking, and hence the landfill cover system could be protected from the damage of wetting-drying cycles.

The changes of CIF of compacted clay based on the effects of wetting-drying cycles are shown in Fig. 9. CIF of compacted clay increased as moisture content decreased, indicating that continuous dehydration leads to the growth in crack area. CIF decreased as clay samples were humidified first and then went down as dehydration continued, indicating that some cracks healed at the beginning of humidification then developed again because of dehydration. The extent of the development of cracks was higher after dehydration than that before humidification. Wetting-drying cycles were the principal reason of cracking in compacted clay. CIF was small before humidification and increased obviously after wetting-drying cycles. The values of CIF of compacted clay based on the effect of four wetting-drying cycles were 0.012, 0.014, 0.023 and 0.032 respectively. As the humidification went on, cohesive force between soil particles weakened and soil particles become severely broken particularly on the surface of soil samples. At the beginning of humidification, some of the cracks developed in dehydration period closed even dismissed resulted from the swelling of soil particles, and they developed in the weakest part of soil sample under the action of consequent drying shrinkage. Therefore the development of cracks increased as the number of wetting-drying cycles increased.

As the increase of FC, the CIF of improved clay decreased firstly and then increased. Under the action of four wetting-drying cycles, CIF declined from 0.031 to 0.0081 as FC increased from 0.05% to 0.3%. But when FC reached 0.5%, CIF rose to 0.017. This may be explained by the fact that at FC>0.3%, more fibers filled the soil voids and adhered to each other to form lumps, which suppressed the contact between soil particles and fibers, and induced less resistance between soil particles and fibers(Harianto et al., 2008).

3.2 Water seepage under cracking of improved clay by straw fiber

When the rainfall intensities were 10mm/d and 50mm/d with rainfall duration at 1h, the water seepage behaviors of these soil samples are shown in Figs 10 and 11. When rainfall intensity was 10mm/d, moisture content of traditional compacted clay liners rapidly grew from 0.11 to 0.333

within one day and declined to 0.259 in the subsequent 5 days of evaporation at 5 cm depth of clay liners, growing from 0.13 to 0.224 in 2.18 days at 10cm depth, increasing slowly to 0.243 in 6 days at 15cm depth. For the clay liners with compacted clay improved by straw fiber (FC=0.3%), moisture content increased from 0.09 to 0.227 and declined to 0.136 in the following 5 days of evaporation at 5 cm depth of clay liners and was little influenced by rainfall intensity at 10 cm and 15 cm depth. When rainfall intensity was 50mm/d, moisture content of traditional clay liners with compacted clay was more significantly correlated to rainfall. At 15 cm depth, moisture content began to grow after 2.8 days and reached 0.309 at 4.83 days. When rainfall intensity was 50mm/d, rainwater had permeated to 10 cm depth where the moisture content rose to 0.161. There was no change of moisture content at 15 cm depth. The permeability of the fissured soil is extremely high. But the permeability decreased gradually to a stable value, which could be attributed to the closure of cracks due to the swelling of clays at increased saturations during the period of rainfall (Li et al., 2011). These results indicated that traditional compacted clay liners lost the anti-seepage ability under the action of rainfall and rainwater could penetrate into landfill. The compacted clay improved by straw fibers had relatively high level of resistance towards cracking and increase of permeability, and could thus be used as the impermeable material for the landfill cover system.

3.3 Hydraulic conductivity of improved clay by straw fiber with cracks

As shown in figure 12, the influence of dry-wet circulation on hydraulic conductivity is remarkable. This graph explains the change of hydraulic conductivity of clay soil modified by straw fiber during drying-wetting cycles for four times, After four times of dry-wet cycles, the hydraulic conductivity of the compacted clay without Straw fiber jumps from 2.33×10^{-8}cm/s to 1.62×10^{-6}cm/s. In the meanwhile, the improved soil with FC=0.3% and 0.5% respectively have the permeability increased to 1.05×10^{-7}cm/s and 8.38×10^{-7}cm/s. It is also observed that the hydraulic conductivity of compacted clay samples is close to equilibrium after three times of dry-wet circulation.

3.4 Strength and deformation of the improved clay

3.4.1 Unconfined compressive strength

The unconfined compressive strength of clay containing straw fiber was shown in Fig. 13. As the increase of strain, the compressive strength grew firstly then decline subsequently. The unconfined compressive strength of clay without fiber additive (FC=0%) peaked at 326.61kPa. The compressive strength increased firstly then decline as the increase of FC and peaked at 459.15kPa as FC increased to 0.3%. The minimum value of unconfined compressive strength of soil used as the impermeable material of landfill was considered to be 200kPa (Taha and Kabir, 2005). In this regard, the compacted clay containing straw fiber could be used in landfill cover system. During unconfined compression tests, the strain-softening, which was most significant in raw compacted clay without fiber additive, gradually weakened as the increase of FC. The results of unconfined compression tests showed that the strengths of the improved clay fluctuated after reaching the peak strength, followed by a dramatic drop.

In the case of FC<0.3%, straw fibers increase the resistance between soil particles and thus improve the stiffness and ductility, which effectively suppresses cracking. In the case of FC>0.3%, the orientation distribution of fibers and excessive contact between fibers induce less resistance between soil particles and fibers, thus generate more fracture planes.

3.4.2 Shear strength

Shear strength and the shear strength index, cohesion(c) and internal friction angle (φ), of clay-fiber mixture were shown in Fig. 14 and Fig. 15. Shear strength grew as the increase of FC in the case of FC<0.3%, peaked at FC＝0.3% and then declined as FC increased (Fig. 14). As shown in Fig. 15, c and φ first increased and then decreased with increasing FC, with the peak values at FC=0.3%. Therefore, the optimum FC was determined to be 0.3%. These findings go against the search of Yetimoglu and Vallejo (Yetimoglu and Salbas, 2003; Lobo-Guerrero and Vallejo, 2010). They found that flexible fibres do not improve the shear strength of soils. The disagreement among the reported results is attributed to the difference in the material properties. Because the clay has stickness, the bonding strength and frictional resistance between the clay and the straw fibres is much larger relative to sands and fibers. Hence, shear strength of the improved clay containing fibers is much larger than the compacted clay.

The c and φ of the clay-fiber mixture were generated though the interaction of horizontal and vertical confining force between soil particles or between particles and fibers. The reinforcement effect of straw fibers resulted from the increase of horizontal as well as vertical constraint force. Cohesive force between soil particles and fibers grew as FC increased in the case of FC<0.3% because the networks formed by fibers could improve the friction between clay particles and thus increase c and φ. In the case of FC>0.3%, excessive fibers adhered to each other, which induces the reduction of c and φ.

4 Conclusions

In order to prevent from the failure of landfill cover system in terms of cracking and permeating during long-term operation, straw fibers extracted from straw were used as an effective soil additive to improve the compacted clay by increasing the anti-seepage ability and strength of landfill cover system. To evaluate the feasibility of clay improved by straw fibers as material of landfill liners, an experimental program was conducted in this study containing four main tasks: (1) observe the cracking performance of improved clay through cracking tests under the action of continuous desiccation and wetting-drying cycles, (2) study the seepage mechanism of the compacted clay improved by straw fiber after wetting-drying cycles through water permeability test, (3) The change of permeability of the clay improved by straw fiber using the environmental soil flexible wall permeameter ,(4) analyze the strength and deformation characteristics of the improved clay through unconfined compression tests and shear tests. The following conclusions can be drawn based on the test results and analysis.

(1) After 25-day continuous desiccation and dehydration, surface shrinkage of compacted clay reached 12.1% and CIF was 0.015. The cracks on the surface were clearly observable. No obvious crack was detected on the surface of compacted clay-fiber mixture, suggesting a strong resistance of the improved clay to cracking. At FC=0.3%, the cracking resistance of improved clay peaked but the increase of the resistance to surface shrinkage was less obvious (CIF and area shrinkage were 0.0013and 10.31%, respectively).

(2) Wetting-drying cycles increased the cracks in clay. Under the action of four wetting-drying cycles, CIF of compacted clay reached 0.032 and cracks had run through the 2cm thick clay sample. The resistance of improved clay to cracking was moderate. CIF decreased firstly and then increased as FC grew. At FC=0.3%, the CIF was only 0.0081 and cracks were shallow, suggesting the strongest resistance of improved clay to cracking. Some cracks became smaller at the beginning of humidification but developed more rapidly as the number of wetting-drying cycles increased.

(3) The anti-seepage ability in clay containing straw fiber was in a relatively high level. With a rainfall intensity of 10mm/d, rainwater had penetrated to a 15 cm depth for the traditional clay cover but a 5 cm depth for the improved clay cover (FC=0.3%) under the action of 4 wetting-drying cycles. Even with an increased rainfall intensity of 50mm/d, the moisture content at the 15 cm depth of improved landfill liners (FC=0.3%) was not influenced.

(4) After four wetting-drying

cycles, the hydraulic conductivity of compacted cohesive soil without being modified by straw fiber increased by two orders of magnitude, suggesting that it completely lost the anti-seepage capability. The permeability of the clay modified by straw fiber(FC=0.3%) was 1.05×10^{-7}cm/s, which basically meets the requirements of landfill anti-seepage system.

(5) For the compacted clay containing straw fibers, unconfined compressive strength and shear strength increased firstly and then declined as the increase of FC. At FC=0.3%, the maximum unconfined compressive strength was 459.15kPa, and the maximum values of shear strength index(c and φ) were 80.9kPa and 21.06°, respectively.

Acknowledgments

This research was supported by the National Basic Research Program of China (973 Program) (2012CB719802); the National Water Pollution Control and Management Science and Technology Major Projects of China (2012ZX07104-002); the Special Fund for Basic Research on Scientific Instruments of the National Natural Science Foundation of China (51279199,50927904,5079143) and Hubei Provincial Natural Science Foundation of China (ZRZ0322).

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Table 1　Chemical composition of clay（%）

SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
58.42	25.23	0.24	0.51	0.12	5.32	2.67

Table 2　Basic physical indexes of clay

ρ_{dmax}/ g/cm^3	W_{opt}	W_L	W_p	I_p	particle size distribution /%			
					>0.05mm	0.05~0.005mm	0.005~0.002mm	<0.002mm
1.65	0.19	48.5	26.2	22.3	12	32	45	11

Table 3　Chemical composition of straw（%）

Ash	HNO_3- C_2H_5OH cellulose	Hemicellulose	Lignin	Fat waxy	Loss
13.52	35.65	26.83	10.44	5.21	8.35

Table 4　Physical properties of straw fiber

Length/mm	Width/um	pH（20℃）	Ash content/%	Oil absorption ratio	Moisture content/%	Breaking strength /cN/tex	Elongation at break /%
1±0.1	20-50	7.73	20	5.78	3.6	12.6~24.5	5.3

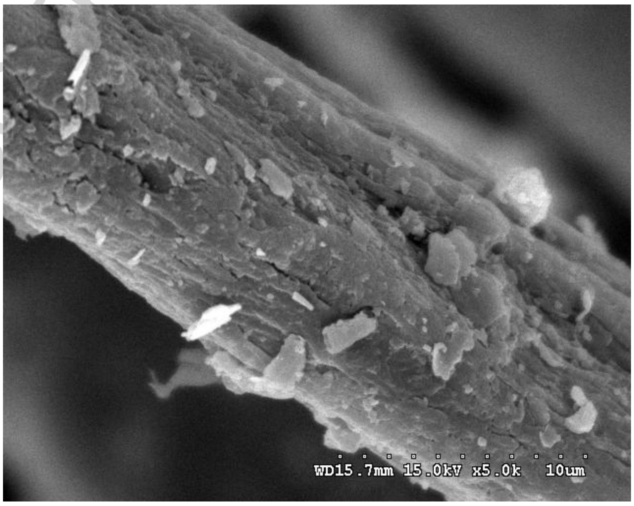


Fig.1　The microstructure of straw fiber

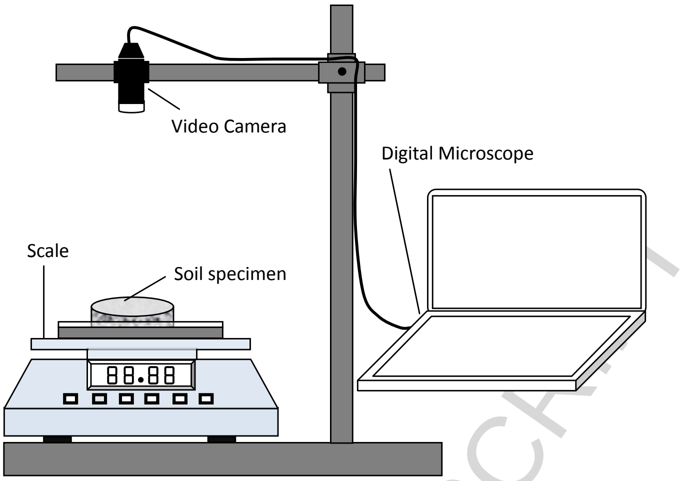


Fig.2 Cracking monitoring device for compacted clay

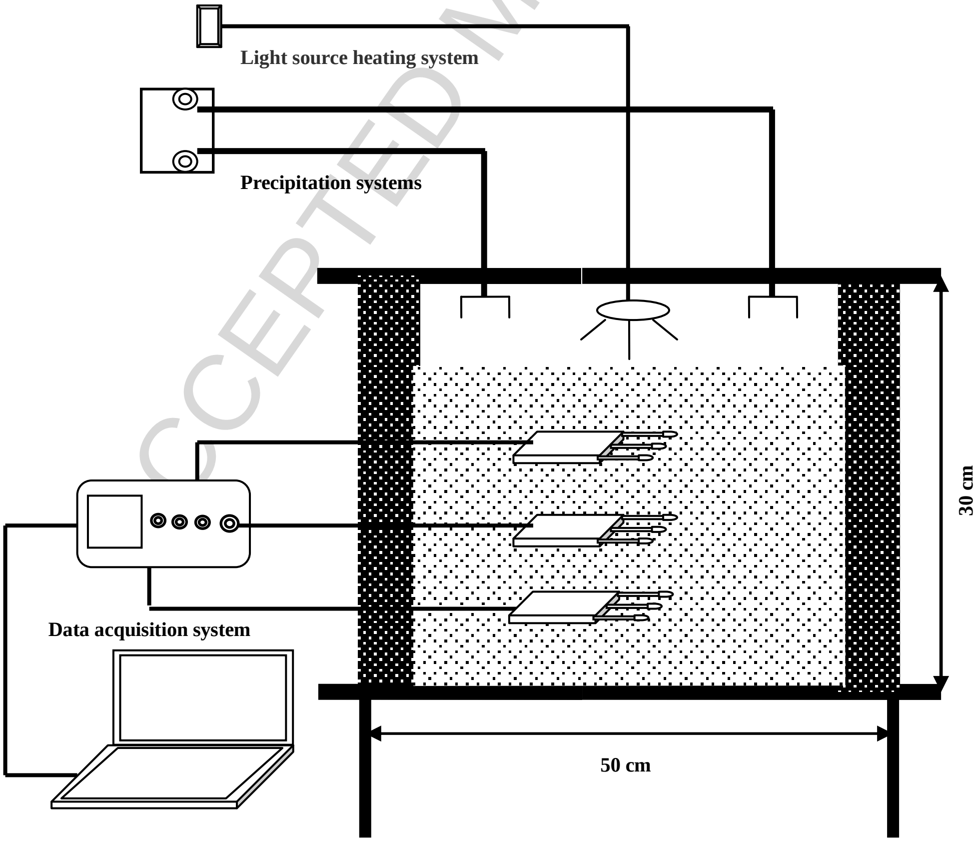


Fig. 3 Water seepage test device for cracked clay

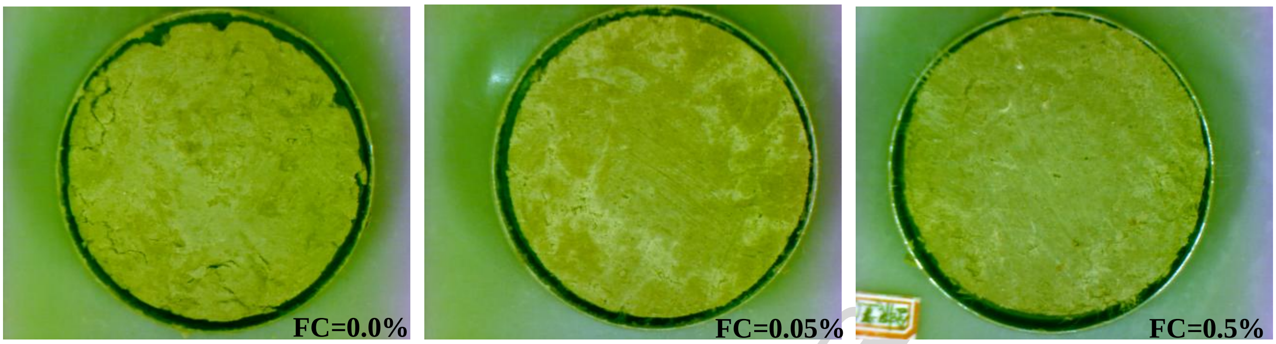


Fig. 4 The development of cracks in clay containing straw fiber under the action of continuous dehydration

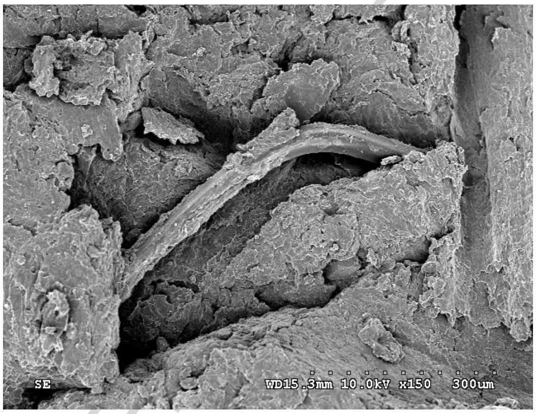


Fig. 5 The microstructure of clay containing straw fiber

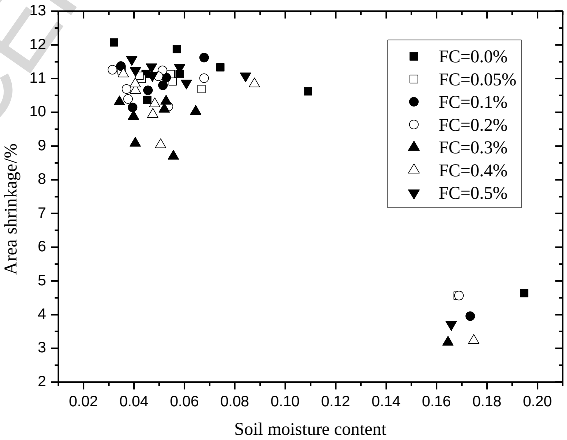


Fig.6 Area shrinkage of clay containing straw fiber under action of continuous dehydration

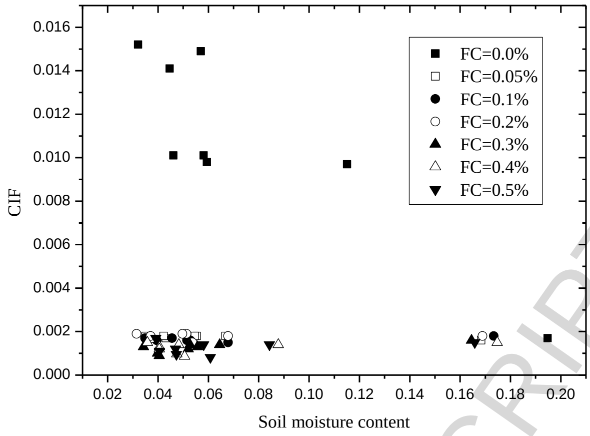


Fig. 7 CIF of clay containing straw fiber under the action of dehydration

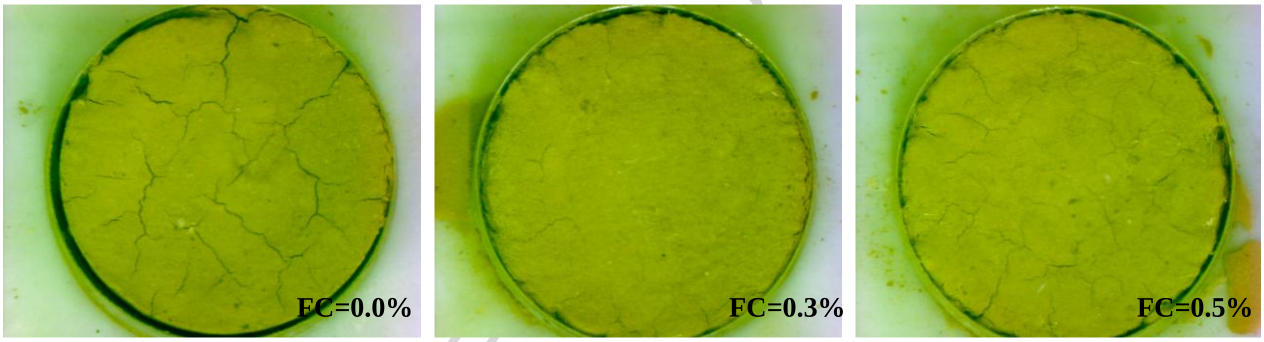


Fig. 8 The development of cracks in clay containing straw fiber under the action of wetting-drying cycles

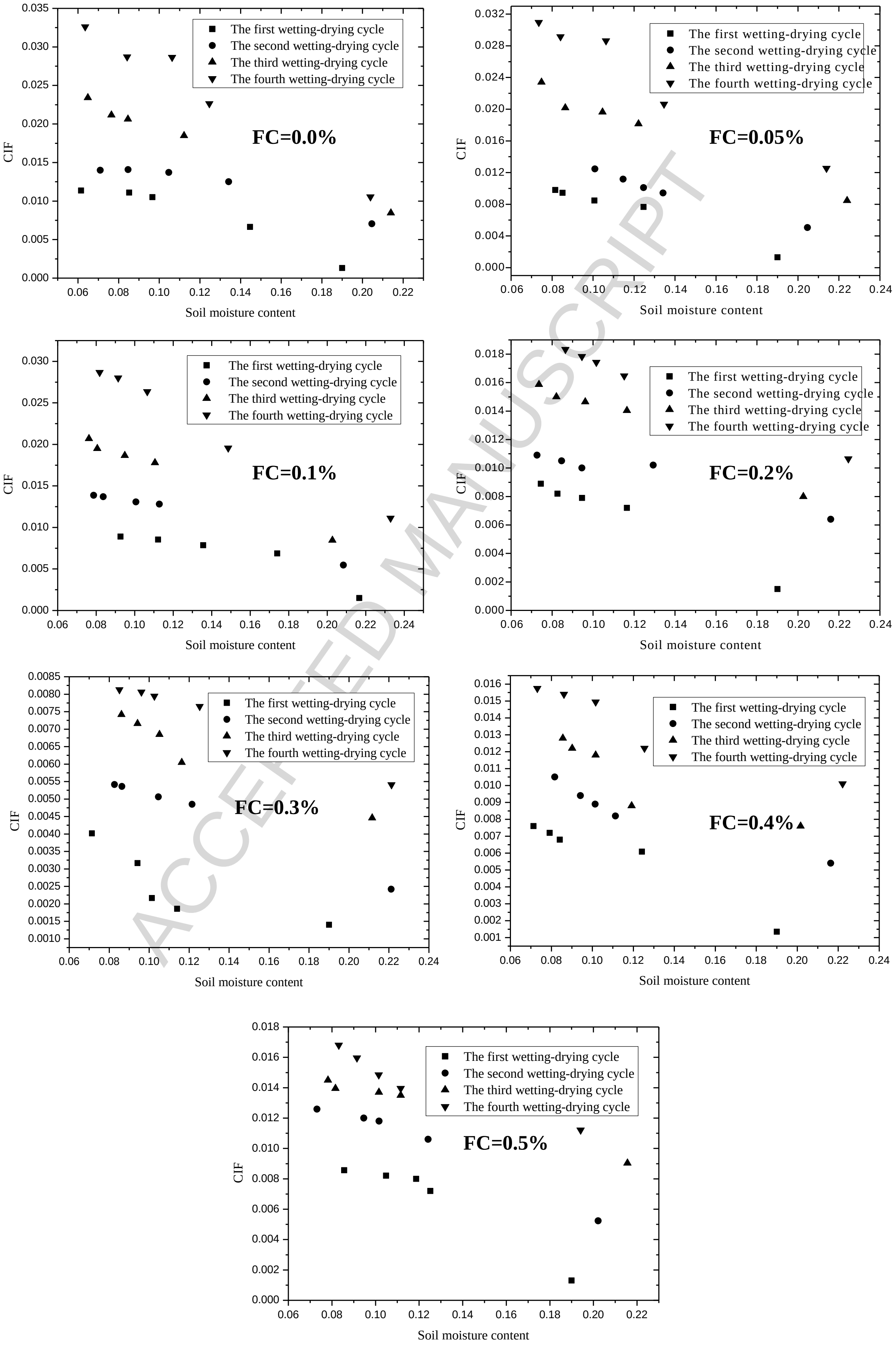
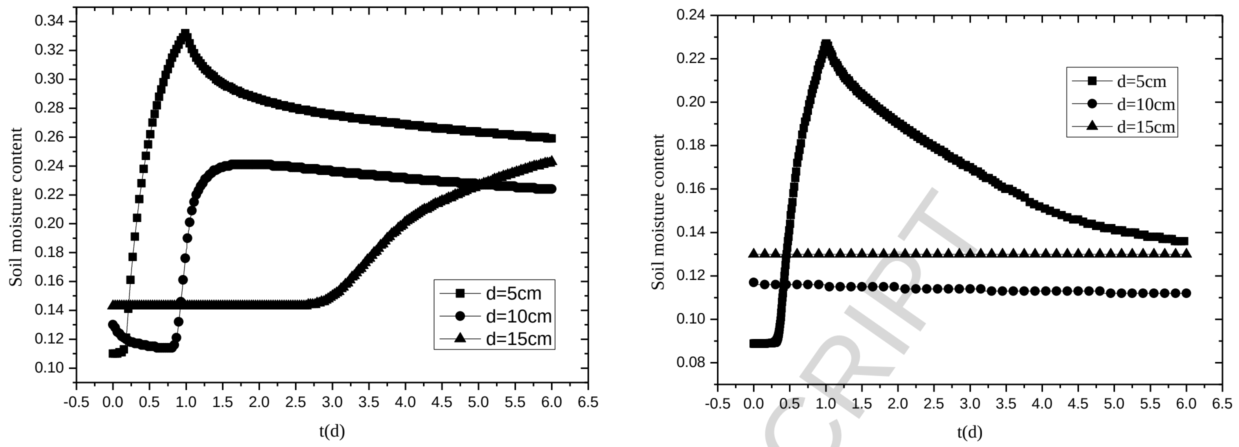
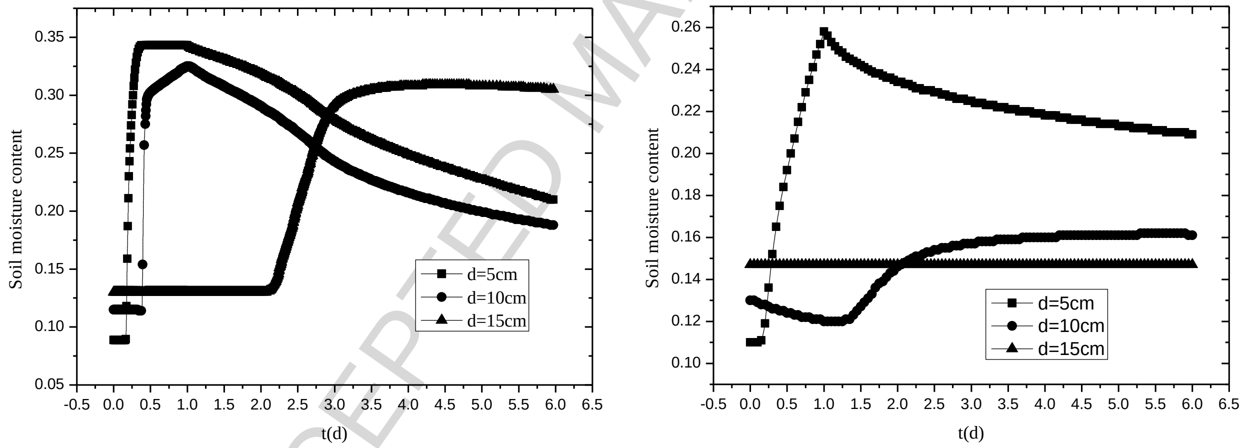


Fig.9 CIF of clay containing straw fiber



(a) Traditional compacted clay liners (b) clay liners improved by straw fiber

Fig. 10 Water seepage in landfill liners in the condition of rainfall (10mm/d)



(a) Traditional compacted clay liners (b) clay liners improved by straw fiber

Fig. 11 Water seepage in landfill liners in the condition of rainfall (50mm/d)

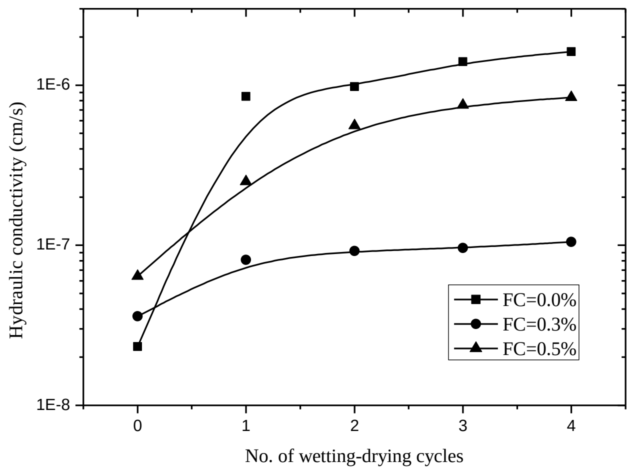


Fig.12 Hydraulic conductivity for different wetting-drying cycles

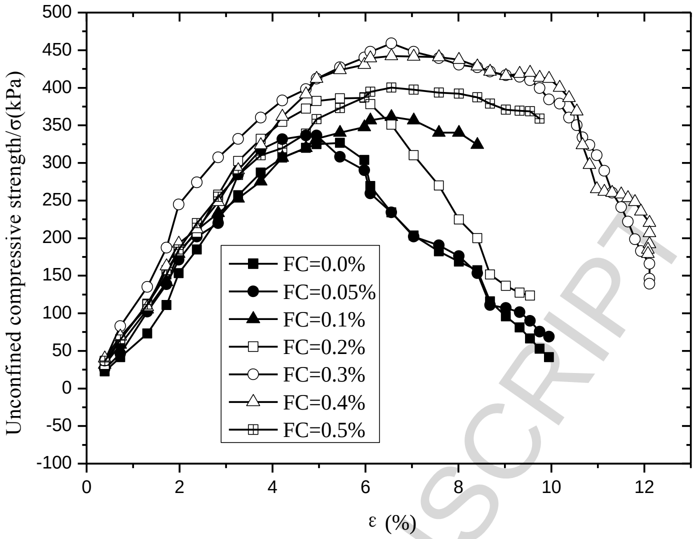


Fig.13 The unconfined compressive strength of clay containing straw fiber

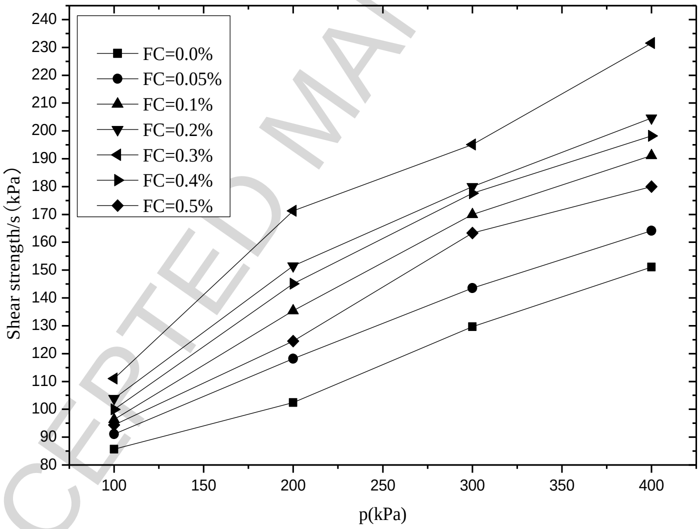


Fig.14 The shear strength of clay containing straw fiber

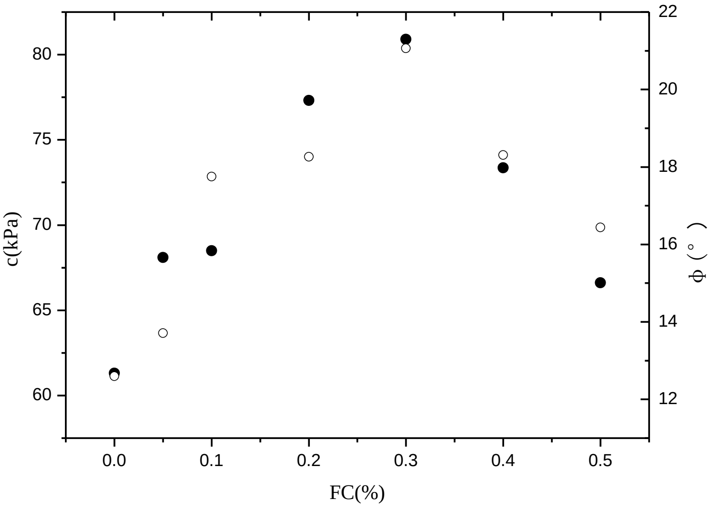


Fig.15 The shear strength index of clay containing straw fiber

- The cracking resistance of improved clay by straw fiber was evaluated.
- The improved clay had higher resistance to cracking than traditional clay.
- The improved clay with fiber content 0.3% had the highest resistance to cracking.
- The unconfined compressive strength increased firstly and then decreased.
- The improved clay had the higher anti-seepage ability than traditional clay.