Experimental Research on the Mechanical Properties of Cotton Stalk Bale – cement-based Material Reinforced Pile

J Shang[1, 2] and X J Yu[1,*]

[1]Civil Engineering, Yancheng Institute of Technology, No.1 Xiwang Road, Yancheng city, Jiangsu, China
[2]Anhui University of Science and Technology, Huainan, China

Corresponding author and e-mail: X J Yu, yuxiaojuan@ycit.edu.cn

Abstract. For reducing environmental pollution from the abandonment and incineration of stalks of crops, a technique that prepares building material with cotton stalk bale and blast furnace slag was studied and the mechanical properties of environmental friendly, energy saving cotton stalk bale – cement-based material reinforced pile were studied through experiment. While cement-soil mixing pile exhibits high compressive strength, its bending strength is low. Experiment was performed to see whether it is feasible to use cotton stalk bale as the reinforcement material of cement and soil. The result shows that the addition of cotton stalk bale increases the toughness, ductility, and mechanical properties, including compressive and bending strength of cement and soil. Impact of different admixture dosages of cotton stalk bales and blast furnace slags on the compressive and bending strength and other mechanical properties of cement and soil were explored. The physical and mechanical properties of cotton stalk bale – cement-based material reinforced pile were considered.

1. Introduction

A massive amount of agricultural associated wastes such as bamboo and stalk [1] and extensive solid waste of blast furnace slag from industrial production could have adverse impact on eco-environment if they are disposed improperly. Smoky haze from burning forest to clear land in Indonesia sparked a diplomatic dispute with Singapore and other surrounding countries in 2015. Smog from India's crop burning sparked panic among citizens in 2016. Haze from crop burning hit a number of cities in North China in November 2016. These events are just the tip of the iceberg in terms of environmental pollution caused by primary, rough disposal of agricultural associated waste in large agriculture producing countries. Therefore, it becomes very urgent to dispose wastes from crop properly and broaden their use. As an excellent reinforcement material [2-5], stalk was used for engineering purpose very long ago. The thousand-year-old Great Wall used stalk to lay the wall and reinforce the foundation. Some scholars have suggested that reinforcement materials like bamboo and stalk may be added to cement-based materials to improve the mechanical properties of the latter. The mechanical properties of soil can be increased by adding bamboo chips thereto [6]. Wiwoho M S et al. [7] studied the use of bamboo waste in place of gravel in aggregate for road pavement. Susila E et al. [8] explored the combined use of bamboo and pile in the reinforcement of soft soil foundation and found that the composite reinforcement of bamboo and pile can solve the problem of low-bearing capacity

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of soft soil foundation in embankment construction. The experiment showed that the bamboo-pile reinforcement system can make embankment more stable and safe. Zea Escamilla E et al. [9] used bamboo material plastered with mortar and cement in building envelope and enabled the same to exhibit long service life and high efficiency. Gupta S et al. [10] tried to make concrete-soil-bamboo column composite material by replacing a part of steel and concrete and the tested column withstood a load of 75kN under 50% of the maximum stress. Cement slab reinforced with bamboo in place of steel bar can be used as accessible roof of roof panel of cost-effective residence, such as roof panel, protecting the environment without compromising structural integrity. The addition of bamboo chips enabled all cement slabs show good ductility before bending failure [11]. Potassium-sodium-soil polymer was reinforced with bamboo fibers and chips to form bamboo reinforced material – a geo high polymer and increase the bending strength of soil – bamboo composite. The addition of bamboo fibers not only increased the bending strength and strain of the composite, but also improved its toughness, turning the failure mode of the material from brittle failure to ductile failure [12, 13]. Bamboo is a kind of ductile material with a certain tensile strength. It is an ideal substitute of steel and can be used to support compressed and bent members [14]. Dai Z H et al. [15] proposed a moso bamboo reinforced soil nail wall – a new retaining structure that uses moso bamboo as soil nail and pile, as well as bamboo grid shotcrete finishing. The experiment showed 2.5-2.8 time's pull-out capacity of bamboo nail in rigid soil and soft clay respectively compared to steel nail, and verified the stability of the bamboo reinforcement system. Li W T et al. [16] improved the bearing capacity of bamboo column by pouring cement mortar in bamboo. Based on real project, Dai Z et al. [17] used bamboo soil nail and bamboo pile in rows as support structure in foundation pit and made finite element simulation analysis on bamboo soil nail. The result showed that bamboo soil nail and bamboo pile in rows can increase the stability of foundation pit significantly and are expected to promote the application of environmental friendly, cost-effective support technology to real projects. Mansur M A et al. [18] studied the role of bamboo grid in improving the performance of cement mortar by experiment and found that bamboo grid is highly ductile and brings toughness to cement mortar, improving the mechanical properties, including tensile strength, bending strength and impact strength of cement mortar significantly. However, the length of reinforcement of bamboo is limited due to various shortcomings of bamboo, including uneven material of bamboo whose different parts have different impact on the mechanical properties of cement-based material, limited length, thin tip, weak nodes, and unreliable and uneasy connection between bamboo materials. Hong Y et al. [19] increased the strength of cement soil by adding basalt fiber therein. According to the experiment, cement soil failed as a whole due to the addition of basalt fiber and exhibited higher strength under the effect of basalt fiber. Sukontasukkul P et al. [20] enhanced the strength of cement oil significantly by adding steel bar and polypropylene fiber therein. While the above researches focused on reinforcement materials indicate that these materials work to a certain extent, there are a number of things to overcome, including the weak nodes and limited length of reinforcement of bamboo, and the high cost of reinforcement materials such as basalt fiber and polypropylene fiber. To address these challenges, this paper puts forward a cotton stalk bale – cement-based material reinforced pile that is made by pouring cement-based grout into cotton stalk bale, and studies the mechanical properties of the pile for pointing the way for recycling of cotton stalk waste and industrial blasé furnace slag and environmental protection.

2. Experimental materials and methods

2.1. Experimental Materials

Soil samples used in the experiment were taken from the soil mass of a foundation pit under construction in Yancheng. Tests were performed against the soil mass according to the *Code for Design of Building Foundation* (GB/T50007-2002) and *Standard for Soil Test Method* (GB/T50123-

1999) for determining the physical and mechanical properties of soil as shown in Table 1. Soil used in the experiment complies with the *Specification for Design of Mix Proportion of Cement Soil* (JGJ/T233-2011) and were crushed after drying. Portland cement P.O42.5 from Conch Cement Factory in Baling, Yancheng, Jiangsu was used.

Blast furnace slag powders from Lianxin Concrete Co., Ltd. in Yancheng, Jiangsu were selected. Slag is an industrial solid waste that pollutes eco-environment and harms human health. When being used in reinforced pile, blast furnace slag powders may improve environment and reduce cement consumption.

Abandoned cotton stalks were collected from the rural area of Jiangsu and tied into bales of two varying lengths as shown in Figure 1(a), (b).

Table 1. Basic physical properties of soil specimens.

Water content	Liquid limit	Plastic limit	Plasticity index	Wet density	Dry density	coefficient of permeability
ω /%	ω_L /%	ω_p /%	I_p /%	ρ /(g·cm^{-3})	ρ_d /(g·cm^{-3})	κ/(cm·s^{-1})
34.3	46.6	21.5	25.1	1.92	1.43	10^{-6}

(a) Length=10mm (b) Length=40mm

Figure 1. Cotton Stalk Bale.

2.2. A subsection

The experiment adopted the orthogonal method and used factors, including cement admixture dosage, S95 blast furnace slag powder admixture dosage, and water cement ratio. Specifically, admixture dosage of cement was 15%, 20% and 35% respectively; admixture dosage of S95 blast furnace slag powder was 20%, 30% and 35% respectively; admixture dosage of cotton stalks was 0.01g/cm^3, 0.02g/cm^3 and 0.03g/cm^3 respectively; water cement ratio was 0.5, 0.55 and 0.6 respectively. The mechanical properties of cotton stalk bale – cement-based material reinforced pile were studied and its mechanism was analyzed. The admixture dosage of S95 blast furnace slag powder was based on that of cement.Below is a table composition of the material of cement, blast furnace slag powder, cotton stalk , water cement ratio in Table 2.

Table 2. Mix proportion.

Code name	Cement	Blast furnace slag powder	Cotton stalk	Water cement ratio
1	15%	20%	0.01	0.5
2	15%	30%	0.02	0.55
3	15%	35%	0.03	0.6
4	20%	20%	0.02	0.6
5	20%	30%	0.03	0.5
6	20%	35%	0.01	0.55
7	25%	20%	0.03	0.55
8	25%	30%	0.01	0.6
9	25%	35%	0.02	0.5

2.3. Experimental methods

Test specimens were prepared according to the *Test Specification for Cement and Cement Concrete for Highway Engineering* (JGJ/E30-2005) by crushing the soil samples after drying. To ensure uniform particles of soil samples used, soil samples were sieved with a 5mm sieve. Cement, soil sample and S95 blast furnace slag powder were weighed based on the mix proportions and put into a mixer for uniform mixing, and then weighed water was added to mix evenly. Before pouring the slurry, a layer of release agent was applied to the inside of the test mode to facilitate the release of test specimen from mode. Cotton stalk bales of varying length of 90mm and 390mm were placed into test modes. Evenly mixed slurry was poured into a 100mm × 100mm × 100mm cubic test mode and a 100mm × 100mm × 400mm prismatic test mode respectively, vibrated and compacted on a vibrating table, and sealed with plastic film after excess slurry was scraped off. Molded specimens were released after 48h and stored in a place with 20±1℃ temperature and more than 90% relative humidity for natural curing to the specified age. Specimens of cotton stalk bale – cement-based material reinforced pile naturally cured to the specified age were taken and tested for compressive strength and bending strength with WDW-50E Electronic Universal Testing Machine. Loading rate was controlled at 0.02mm/min, and the mean of three parallel specimens, accurate to 0.1MPa, was taken for each group of tests. Micro morphology of hydration products of cotton stalk bale – cement-based material reinforced pile was observed, and bond interface and energy spectrum analysis was made with QUANTA200 Scanning Electron Microscope from FEI. In the experiment, 162 specimens were made for mechanical property test. Specimens of two varying dimensions are shown in Figure 2(a) and (b).

(a) 100mm*100mm*100mm

(b) 100mm*100mm*400mm

Figure 2. Cement soil solidified sample with cotton stalk.

3. Results and analyses

3.1. Failure Mode of Reinforced Pile Specimens

The specimens of cotton stalk bale – cement based material reinforced pile failed under compression in four basic modes.

When a small dosage of stalk was admixed, i.e. low "reinforcement" rate, say 0.01g/cm^3 of cotton stalk, in combination with low strength of the hardened body and low compressive strength of the cotton stalk bale – cement-based material reinforced pile in this experiment, the specimen failed in the form of chipping off as shown in Figure 3. The reason why the specimen failed in this mode is because hardened bodies wrapped with cotton stalk bale demonstrated low strength, cotton stalk bale showed low compressive strength due to low dosage of admixture, irregular cross cracks appeared on the specimen as pressure increased and generally chipped off after compressive failure in the compressive strength test.

When a small dosage of stalk was admixed, i.e. low "reinforcement" rate, say 0.01g/cm^3 of cotton stalk, in combination with high strength of the hardened body and high compressive strength of the cotton stalk bale – cement-based material reinforced pile in this experiment, the specimen failed in the form of pyramid as shown in Figure 4. Such failure resulted from the Hoop effect. Specifically, compressive stresses imposed shear stresses in the 45° direction when the specimen was pressed, the failure plane took the form of a 45° bevel and the part with hardened body fell off took the shape of a pyramid.

Figure 3. Brittle fracture.

Figure 4. Diagonal conical failure.

When a high dosage of stalk was admixed, i.e. high "reinforcement" rate, say 0.02g/cm^3 or 0.03g/cm^3 of cotton stalk, in combination with high strength of the hardened body and high compressive strength of the cotton stalk bale – cement-based material reinforced pile in this experiment, the specimen failed in the form of sliding as shown in Figure 5. The reason why the specimen failed in this mode is because cotton stalk bales failed as they firstly reached their limit for compressive load under the action of stress, causing damage to the overall consistency inside the specimen, and consequently, the external hardened body wrapped with cotton stalk bales fell off. Cracks developed and extended along cotton stalk bales on the specimen in this mode.

When a high dosage of stalk was admixed, i.e. high "reinforcement" rate, say 0.02g/cm^3 or 0.03g/cm^3 of cotton stalk, in combination with low strength of the hardened body and low compressive strength of the cotton stalk bale – cement-based material reinforced pile in this experiment, the specimen failed in the form of network as shown in Figure 6. The reason why the specimen failed in this mode is because the hardened body wrapped with cotton stalk bales demonstrated low strength and was unable to withstand stress as they firstly reached their limit for compressive load due to low strength in the compressive strength test. Here cotton stalk bale in the specimen helped resist stress and was directly under pressure. Crack appeared on the specimen in the same direction as pressure, leading to local falling off of the external hardened body until cotton stalk bales reached the limit of compression, and the compressive strength was determined at this point.

Figure 5. Sliding failure.

Figure 6. Crack failure.

The specimens of cotton stalk bale – cement-based material reinforced pile failed in 5 basic modes in the bending strength test. Similar to the compound comprising the cotton stalk bales with tendrils mesh structure similar to a reinforcement cage and the hardened body generated by cement-based cementitious mixture that withstands the bending load, bending strength of reinforced pile specimens was provided by a compound, and the fracture morphology of specimens failed under the bending load took the form of plastic failure.

When a small dosage of stalk was admixed, i.e. low "reinforcement" rate, say 0.01g/cm^3 of cotton stalk, in combination with high strength of the hardened body of cement-based cementitious mixture, and insufficient bearing capacity of the compound comprising cotton stalk bales and the hardened body generated by cement-based cementitious mixture, the reinforced pile specimen failed under the bending load in the form of failure caused by excessive deflection as shown in Figure 7. In the bending strength test, a specimen was divided into three pieces after being placed under the bending load, resulting in excessive deflection in the middle, i.e. excessive linear displacement, and two visible cracks appeared in the middle of the specimen.

When a small dosage of stalk was admixed, i.e. low "reinforcement" rate, say 0.01g/cm3 of cotton stalk, in combination with high strength of the hardened body of cement-based cementitious mixture in this experiment, the specimen failed in the form of rapture failure of cotton stalk bale as shown in Figure 8. The reason why the specimen failed in this mode is because the external hardened body wrapped with cotton stalk bales demonstrated high strength, while a small dosage of cotton stalk bales was admixed. In the bending strength test, a bending load was applied to the specimen, the cotton stalk bales withstood the bending load when the external hardened body of cement-based cementitious mixture reached the bending limit, and finally broke as the bending load increased.

Figure 7. Excessive deflection failure.

Figure 8. Cotton stalk breakage.

The reinforced pile specimen showed low bearing capacity when the external hardened body of cement-based cementitious mixture demonstrated low strength. In the bending strength test, a bending load was applied to the specimen, the external hardened body wrapped with cotton stalk bales failed in the form of sliding failure of the reinforced pile and the form of lower supporting point failure with hardened body falling off as shown in Figure 9 and Figure 10.

Figure 9. Sliding failure.

Figure 10. Support point failure.

When a high dosage of stalk was admixed, i.e. high "reinforcement" rate, say $0.02g/cm^3$ or $0.03g/cm^3$ of cotton stalk, in combination with high strength of the hardened body of cement-based cementitious mixture, and high bearing capacity of the specimen of the compound comprising cotton stalk bales and the hardened body generated by cement-based cementitious mixture, the specimen failed under bending load in the form of the upper load face failure of cotton stalk bale as shown in Figure11. Because of the high strength of the external hardened body wrapped with cotton stalk bales and the high dosage of cotton stalk bales admixed, the reinforced pile specimen was placed under a bending load, the external hardened body of cement-based cementitious mixture and cotton stalk bales withstood the bending load together and the upper load face failed as the bending load increased in the bending strength test.

Figure 11. Pressure surface failure.

3.2. The mechanism for cotton stalk bale to toughen cement-based material

Cotton stalk bales may toughen cement-based materials. As the load on specimens increased, cracks on reinforced pile specimen gradually developed into larger micro-factures, of which the extension and development can be restricted by cotton stalk bales. When the stress applied to the specimen reached the ultimate load, a pull-out effect occurs due to the lack of cohesion on part of the interface between cotton stalk bale and hardened body, consuming large amounts of energy while overcoming friction between cotton stalk bale and hardened body. Consequently, the destructive effect was mitigated and a certain degree of ductile failure was observed on the specimen. A firmly bonded interface between cotton stalk bale and cement-based material forms a netted structure inside the hardened body to control the development of the cracks.

3.3. Impact of admixing blast furnace slag powder on the mechanical properties of cotton stalk bale – cement-based material reinforced pile

The compressive strength of the specimen of cotton stalk bale – cement-based material reinforced pile went up significantly as the dosage of S95 blast furnace slag powder admixed increased. The addition of S95 blast furnace slag powder can prevent cracks caused by heat of hydration inside the reinforced pile, reduce volume expansion cracks caused by base effect, and absorb substances such as calcium hydroxide generated from cement hydration so as to lower the volume of calcium hydroxide crystal, decrease the porosity of the hardened body of reinforced pile, compact the internal structure, improve the microstructure of the hardened body, and increase the compressive strength of the specimen. At the age of 28 days, the compressive strength of the specimen increased by 31% for 30% blast furnace slag powder admixed compared to 20% blast furnace slag powder admixed. The compressive strength of the specimen increased by 8% for 35% blast furnace slag powder admixed compared to 30% blast furnace slag powder admixed. Therefore, the optimal mix proportion of S95 blast furnace slag powder that maximized the compressive strength of the specimen was 35%. The change of compressive strength in relation to the dosage of S95 blast furnace slag powder admixed is shown in Figure12.

The bending strength of the specimen of cotton stalk bale – cement-based material reinforced pile increased following a slight decrease as the dosage of S95 blast furnace slag powder admixed increased. The bending load was withstood by the compound comprising the cotton stalk bales with tendrils mesh structure similar to a reinforcement cage and the hardened body generated by cement-based cementitious mixture. In the bending test against the specimen, the bending strength consisted of the bond force inside the hardened body of cement-based cementitious mixture and the bond stress of cotton stalk bales. Therefore, the dosage of S95 blast furnace slag powder admixed had less impact on the bending strength than the dosage of cement and cotton stalk bales admixed. The admixing of S95 blast furnace slag powder reduced the heat of hydration of grout mix upon curing and improved the internal adhesion inside the hardened body by reducing the internal porosity. In this experiment, the optimal mix proportion of S95 blast furnace slag powder that maximized the bending strength of the specimen was 35%. At the age of 28 days, the bending strength of the specimen reduced by 3% for 20% blast furnace slag powder admixed compared to 30% blast furnace slag powder admixed. The bending strength of the specimen increased by 3% for 35% blast furnace slag powder was admixed compared to 30% blast furnace slag powder admixed. The change of bending strength in relation to the dosage of S95 blast furnace slag powder admixed is shown in Figure13.

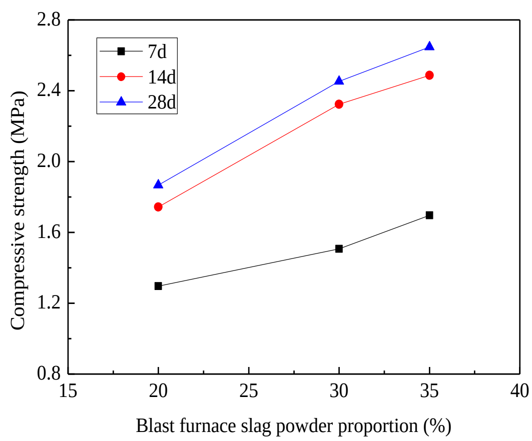

Figure 12. Compressive strength variation with blast furnace slag powder proportion.

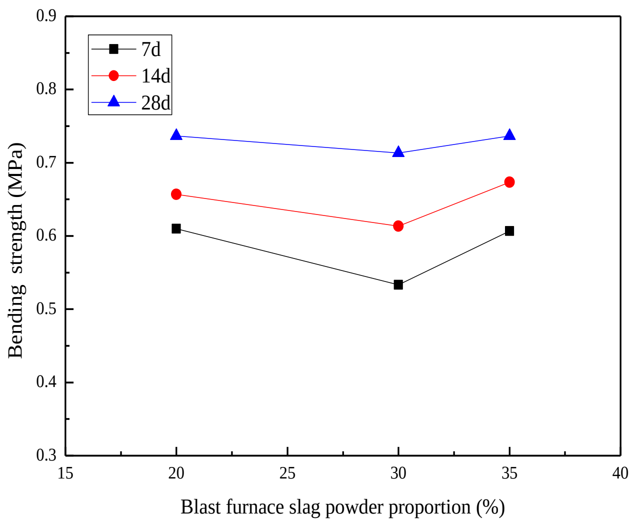

Figure 13. Bending strength variation with blast furnace slag powder proportion.

3.4. Impact of dosage of admixing of cotton stalk bales on the mechanical properties of reinforced pile

The compressive strength of the specimen of cotton stalk bale – cement-based material reinforced pile went up significantly as the dosage of cotton stalk bale admixed increased. The load applied to the specimen was withstood by the hardened body of cement-based cementitious mixture and the cotton stalk bale together. The compressive capacity of cotton stalks was improved significantly by tying them into bales. In the compressive strength test against the specimen, the addition of cotton stalk bale increased the compressive strength of the specimen greatly. When excessive cotton stalk bale was admixed, say 0.03g/cm^3 in this experiment, the large volume of the cotton stalk bale led to volume expansion of the protective layer of the external hardened body wrapped with cotton stalk bales due to squeezing and affected its overall performance, resulting in a slight decline in compressive strength. At the age of 28 days, the compressive strength of the specimen increased by 0.2% for 0.02g/cm^3 of cotton stalk bale admixed compared to 0.01g/cm^3 of cotton stalk bale admixed. The compressive strength of the specimen reduced by 6% for 0.03g/cm^3 of cotton stalk bale admixed compared to 0.02g/cm^3 of cotton stalk bale admixed. Therefore, the optimal mix proportion of cotton stalk bale that significantly improved the compressive strength of the specimen was 0.02g/cm^3. The change of compressive strength in relation to the dosage of cotton stalk bale admixed is shown in Figure14.

The addition of cotton stalk bale significantly improved the bending strength of the specimen of reinforced pile. As a kind of "reinforcement" material similar to steel bar, cotton stalk bale played a role in reinforcing the hardened body of cement-based cementitious mixture. The bending load was withstood by the compound comprising the cotton stalk bales with tendrils mesh structure similar to a reinforcement cage and the hardened body generated by cement-based cementitious mixture. The bending strength of the specimen was provided by the compound, and its bending load was resisted by the bond force inside the hardened body of cement-based cementitious mixture and the bond stress of cotton stalk bales. As the netted structure of cotton stalk bale increased the bond stress, an appropriate increase in the dosage of cotton stalk bale admixed could compact the bonding interface between the cotton stalk bale and the internal of hardened body to improve the bending strength. When excessive cotton stalk bale was admixed, its large volume led to volume expansion inside the hardened body due to squeezing, resulting in a slight decline in bending strength. At the age of 28 days, the bending strength of the specimen increased by 14% for 0.02g/cm^3 of cotton stalk bale admixed compared to 0.01g/cm^3 of cotton stalk bale admixed. The bending strength of the specimen reduced by 6% for 0.02g/cm^3 of cotton stalk bale admixed compared to 0.03g/cm^3 of cotton stalk bale admixed. Therefore, the optimal mix proportion of cotton stalk bale that maximized the bending strength of the specimen was 0.02g/cm^3. The change of bending strength in relation to the dosage of cotton stalk bale admixed is shown in Figure15.

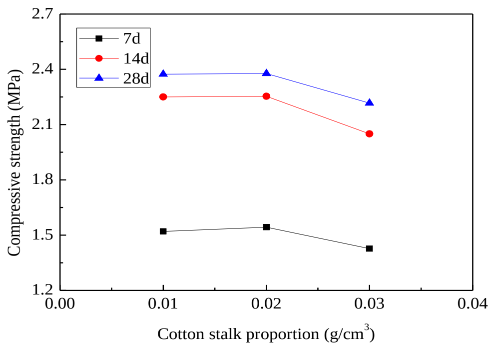

Figure 14. Compressive strength variation with cotton stalk proportion.

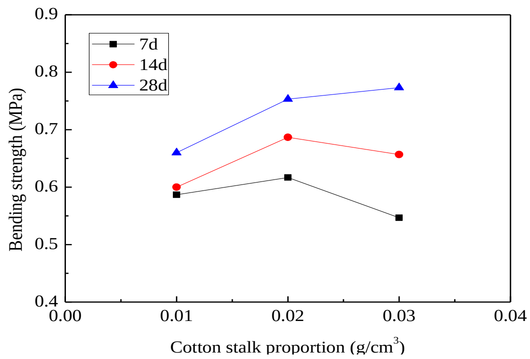

Figure 15. Bending strength variation with cotton stalk proportion.

3.5. Mechanism analysis

The cotton stalk bale – cement-based material reinforced pile is a kind of material prepared with cotton stalk bale as "reinforcement" material and Portland cement, soil, S95 blast furnace slag powder as cementitious mixture in proportion. Its mechanical properties mainly depend on the coordination of the structural strength of cotton stalk bale as the reinforcement material and the physical change and chemical reaction of cement-based reinforcement material. Cotton stalks and different groups of specimens of cotton stalk reinforced pile were analyzed with SEM scanning electron microscope. The surface micro morphology of cotton stalks is shown in Figure16. Cotton stalks with rough surface can strengthen the bonding of the interface with the cementitious mixture. The surface micro morphology of cotton stalks is shown in Figure17.

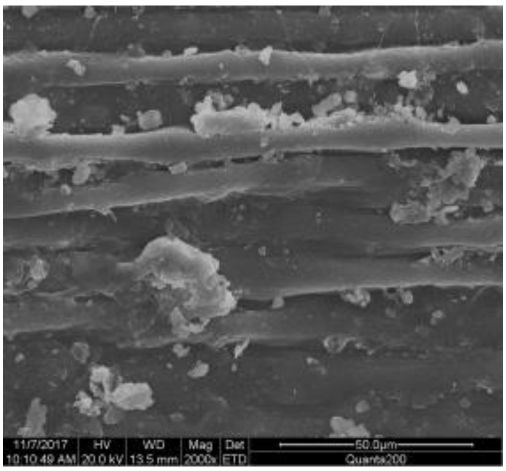

Figure 16. SEM micrograph of cotton straw.

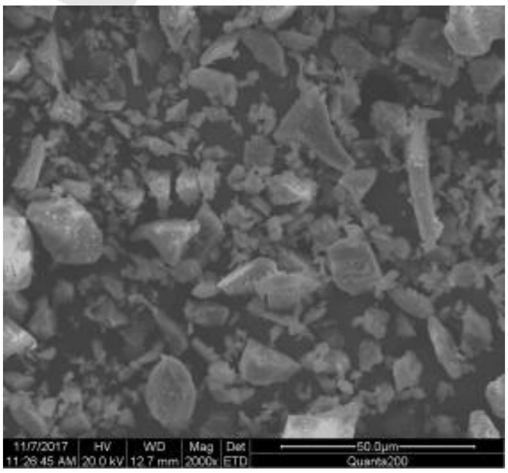

Figure 17. SEM micrograph of blast furnace slag powder.

There are hydration and hydrolysis of cement, interaction between soil particles and cement hydrates, and carbonation in the cotton stalk bale – cement-based material reinforced pile. The curing action of its mixture mainly comes from the hydration, ion exchange, pozzolanic and carbonizing reactions of cement. Once water is added in the cement mixture, a hydration reaction between cement and water, products of the reaction cover the soil particles and enabled the same to gain strength. Main ingredients of Portland cement include tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetra calcium aluminoferrite, and gypsum (i.e. calcium sulfate). Hydrates consist of calcium hydroxide, calcium silicate hydrate gel, calcium ferrite hydrate gel, ettringite and other hydrate gel.

The cotton stalk bale, as “reinforcement” material, acts as a complete skeleton. Cement-based cementitious mixture poured in the cotton stalk bale warps up and integrates with the same after setting and hardening and provides strength after curing. The compressive strength of cotton stalk bale – cement-based material reinforced pile is provided by the external hardened body and cotton stalk bale. SEM micro morphology of the same magnification of the cement-based hardened bodies using mix proportions of groups 1, 6 and 7 at age of 28 days is shown in Figure18, Figure19 and Figure20. Ingredients of micro-area inferred through EDS analysis consist mainly of elements, including calcium (Ca), aluminum (Al), silicon (Si) and oxygen (O). It can be inferred that the micro-area consist of a small amount of silicon dioxide (SiO2) and aluminum oxide (Al_2O_3) particles covered by gel in soil and slag, and plenty of substances such as calcium hydroxide crystal ($Ca(OH)_2$), calcium silicate hydrate gel (i.e. CSH gel), calcium aluminate hydrate gel (i.e. CAH gel), and Calcium sulfoaluminate hydrate (i.e. ettringite).

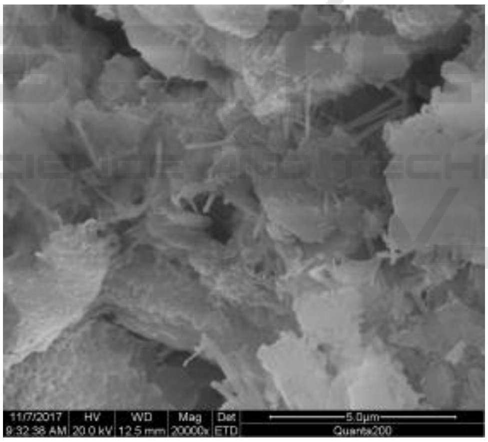

Figure 18. SEM micrographs of group 1 tested specimen.

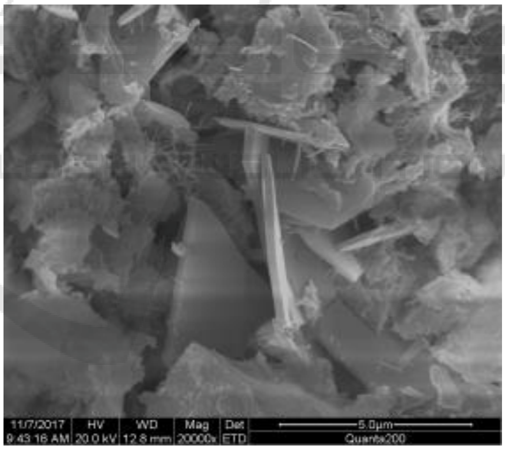

Figure 19. SEM micrographs of group 6 tested specimen.

SEM figure of group 1 shows sparse distribution of calcium hydroxide and ettringite crystals, where the needle shaped substances are ettringite crystals, and crystals covered by CSH gel do not bind tightly together. With a low content, calcium hydroxide and ettringite crystals of group 1 are relatively small.

SEM figure of group 6 shows relatively tighter distribution of calcium hydroxide crystals than group 1 and substances like calcium hydroxide crystal covered by CSH gel, where the needle shaped substances are ettringite crystals covered by external gel, and crystals bind more tightly than group 1. The content of calcium hydroxide crystal, CHS gel and ettringite is higher than group 1, and crystals are relatively large.

SEM figure of group 7 shows even tighter distribution of calcium hydroxide crystals than group 6 and calcium hydroxide crystals tightly covered by CSH gel, where the needle shaped substances are ettringite crystals covered by external gel, and crystals bind more tightly than group 6. The content of calcium hydroxide crystal, CSH gel and ettringite is higher and crystals are much larger than group 6.

According to the data of the compressive strength test against the cotton stalk bale – cement-based material reinforced pile, compressive strength in descending order is group 7 > group 6 > group 1, verifying that the tighter bonding between crystal structures in SEM micro morphology, the more crystals, the higher compressive strength.

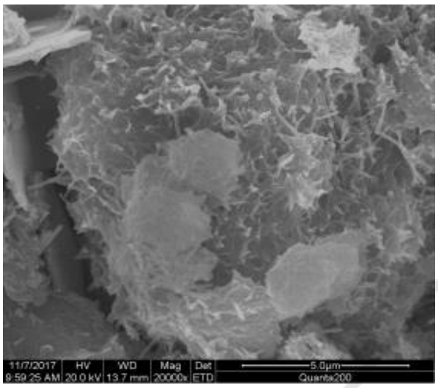

Figure 20. SEM micrographs of group 7 tested specimen.

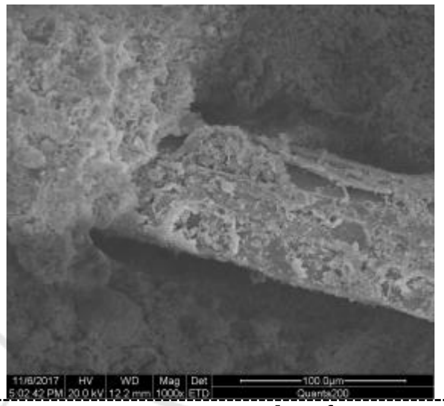

Figure 21. SEM micrographs of group 1 cotton straw and cement soil interface.

The bending strength of the cotton stalk bale – cement-based material reinforced pile mainly comes from the cohesive force inside the external hardened body and at the interface between cotton stalk bale and hardened body. SEM microanalysis was made on the bonding between the surface fiber of cotton stalk bale and the internal of hardened body. Micro morphology of the same magnification of the bonding interface between the cement-based hardened body and the cotton stalk bale using mix proportions of groups 1, 6 and 7 at age of 28 days is shown in Figure21, Figure22 and Figure23.

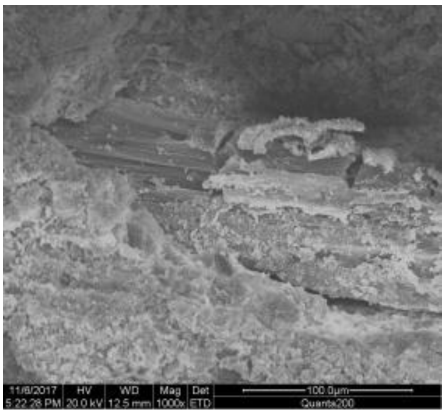

Figure 22. SEM micrographs of group 6 cotton straw and cement soil interface.

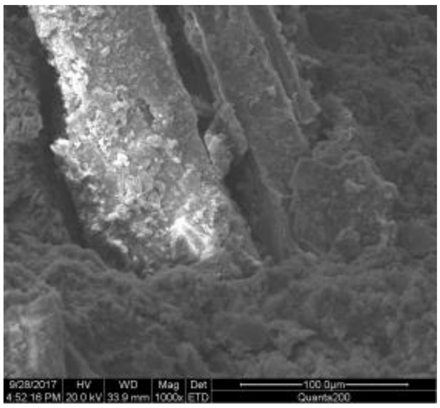

Figure 23. SEM micrographs of group 7 cotton straw and cement soil interface.

SEM figure shows the bonding part between cotton stalk bale and hardened body consisting of fibers at the surface of cotton stalk bale and micro morphology of the hardened body. It can be observed that cotton stalks and hardened body of group 1 do not bond tightly, with gaps in the bonding part, and the surface is covered by a small amount of gel.

Cotton stalks and hardened body of group 6 bond more tightly, and the surface is covered by plenty of gels that fully bond with cotton stalks.

Cotton stalks and hardened body of group 7 bond even more tightly than group 7, demonstrating better bonding effect, and the surface is covered by more gels that fully bond with cotton stalks compared to group 6.

According to the data of the bending strength test against the cotton stalk bale – cement-based material reinforced pile, bending strength in descending order is group 7 > group 6 > group 1, verifying that the tighter bonding of interface between cotton stalks and hardened body in SEM micro morphology, the more gels on the surface of cotton stalks, the higher interface adhesion, the higher blending strength.

4. Conclusions

Based on the research on the mechanical properties of the cotton stalk bale – cement-based material reinforced pile, it can be concluded as follows:

1.The hook structure of tendrils of cotton stalk bale may enhance the bond stress, and the addition of cotton stalk bale significantly improve the toughness of reinforced pile that demonstrates good mechanical properties, indicating the "reinforcement" effect of cotton stalk bale and verifying the feasibility of adding cotton stalk bale to reinforced pile.

2.The addition of cotton stalk bale improve the mechanical properties, and the compressive strength and bending strength reach 3.4MPa and 1.0MPa, higher than traditional cement-soil pile, verifying the feasibility of improving cement-soil pile with cotton stalk bale – cement-based material reinforced pile.

3. The addition of 35% of blast furnace slug powder provides good compressive strength and bending strength, improving the mechanical properties of reinforced pile.

4. In this experiment, the optimal mix proportions that optimize the mechanical properties of cotton stalk bale – cement-based material reinforced pile are 25% of cement, 35% of S95 blast furnace slag powder, 0.02g/cm3 of cotton stalk bale, and 0.5 of water/cement ratio, providing the theoretical basis for the application of cotton stalk bale – cement-based material reinforced pile for engineering purposes.

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