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EXPERIMENTAL STUDY OF THE MECHANICAL PROPERTIES OF BRICKS MADE FROM DREDGED SILT

EKSPERIMENTALNA ŠTUDIJA MEHANSKIH LASTNOSTI OPEK IZDELANIH IZ REČNEGA ALI MORSKEGA MULJA

Jian Zhang, WenBin Zhang, Xiangliang Zhu
Nanjing Vocational Institute of Transport Technology, Nanjing, China

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Numerous dredging and desilting projects in harbor and waterway transportation initiatives generate substantial quantities of dredged mud. Traditional methods, such as blowing and filling, occupy land resources and lead to secondary pollution. The offshore disposal of mud incurs high costs and environmental pollution. Consequently, this paper proposes a silt brick-making method devoid of sintering, autoclaving, and pressing. After a designated maintenance period, the silt bricks are examined to assess the influence of cement, initial moisture content, and age on their compressive and flexural strength. It is feasible to prepare silt bricks by mixing additive materials with silt, followed by molding, vibration, maintenance, demolding, and additional maintenance. As the age increases, the slope of the stress-strain curve for specimens at 1.0× and 1.5× the liquid limit increases accordingly. As the age increases, the slope of the stress-strain curve of the specimen increases, albeit not as rapidly as at 1.5× the liquid limit. The strain at failure remains consistent, primarily within the range of 2–3 %. Silt bricks containing cement-doped marine dredged sludge exhibit increased compressive and flexural strengths with higher cement doping levels, demonstrating a linear relationship between the two. Moreover, as the cement doping and maintenance age increase, the compressive modulus of silt bricks gradually increases, indicating an associated increase in brittleness. The research findings offer a theoretical framework for sintering-free, autoclaved, and pressed dredging silt bricks. This contributes to advancing offshore geotechnical disposal technology in China and holds reference value.

Keywords: silt bricks, dredged mud, compressive strength, flexural strength, cement doping

Številni projekti izkopavanja, poglabljanja in čiščenja vodnih transportnih poti ter pristanišč, je povzročilo precejšnje ekološko neprimerno odlaganje in skladiščenje odpadnega blata oz. mulja. Tradicionalne metode kot sta razpihovanje in/ali polnjenje določenega prostora z odvečnim muljem, zavzemajo velike površine ter povzročajo zato sekundarno onesnaževanje. Odlaganje odvečnega mulja daleč stran od rečnih korit ali pristanišč je tudi drago. Posledično avtorji v tem članku opisujejo alternativno rešitev izdelave opek iz rečnega mulja oz. blata. Avtorji predlagajo postopek izdelave opek brez sintranja, obdelave v avtoklavih in stiskanja surovcev. Po določenem času so izdelane opeke preiskali in ocenili njihovo kakovost. Ugotavljali so vpliv dodatka cementa, vsebnosti začetne vlage in staranja na tlačno in upogibno trdnost opek. Pri postopku izdelave te vrste opek je primerno uporabljati izbrane dodatke, mešanico vibrirati, utrjevati, modelirati, odstranjevati iz modelov in ponovno utrjevati. S staranjem nagib krivulje napetost-deformacija (σ–ε) preizkušancev narašča pri enkratni in 1,5 kratni mejni vsebnosti vlage. S časom staranja nagib krivulje σ–ε preizkušancev narašča, čeprav ne tako hitro kot pri 1,5 kratni mejni vsebnosti vlage. Deformacija in porušitev preizkušancev ostaja nespremenjena v območju med 2 % in 3 %. Opeki iz morskega mulja se s povečevanjem dodatka cementa linearno povečujeta tudi tlačna in upogibna trdnost. Povečevanje vsebnosti dodanega cementa in podaljševanje časa staranja izdelanih opek povečuje njihov tlačni modul in tudi z njim povezano krhkost. Ugotovitve te raziskave, po mnenju avtorjev, predstavljajo teoretično podlago za nesintrane, neavtoklavirane in nestiskane opeke iz rečnega in/ali morskega blata. Ta raziskava predstavlja referenčno vrednost in tako prispeva k naprednemu reševanju problemov geotehniške tehnologije odlaganja blata/mulja na Kitajskem.

Povzetek: čiščenje, širjenje in/ali poglabljana rečnega ali morskega dna, opeka izdelana iz rečnega/morskega blata ali mulja, tlačna in upogibna trdnost, dopiranje s cementom

1 INTRODUCTION

To improve water quality, maintain the average flood-discharge capacity of rivers, promote economic development in port industrial zones, and ensure smooth water transportation, dredging and desilting port and waterway projects are essential, resulting in large amounts of dredged silt. Dredged mud is characterized by a high water content, compressibility, porosity, fines content, low strength, and low permeability. It might contain heavy metals and organic matter, resulting in a prolonged consolidation period and challenges in direct project utilization. Various disposal methods for dredged mud are employed based on the location of the dredging project. Inland dredged mud often undergoes physical and thermal treatment.[1,2] Physical treatment involves placing dredged mud in land dumps. While simple, this method requires significant agricultural land occupation and can lead to environmental pollution. Thermal treatment involves heating through sintering to convert dredged mud into construction materials. However, this method has limited processing capacity, high costs, and challenges in large-scale adoption. Two primary methods are used for disposing of marine dredged mud: blowing and filling. However, blowing and filling construction often spreads mud and water outside the cofferdam, leading to second-

*Corresponding author's e-mail:
beifangnanhai19@163.com (Jian Zhang)

ary pollution. The alternative method is mud dumping, which, due to its heavy metal, nitrogen, phosphorus, and other elements, can impact on the effective development and utilization of marine resources and cause irreparable damage to the marine environment. Moreover, marine dumping is increasingly constrained by various factors.

Two general methods exist for utilizing dredged sludge in engineering materials production: thermal treatment and solidification. The thermal treatment method can enhance the value of dredged mud.[3] Yet, it demands a lot of energy, reaching temperatures of 1200–1500 °C, and generates substantial solid and gaseous waste, leading to air and solid-waste pollution. Moreover, the calcination process is intricate, temperature control is challenging, equipment is fixed, substantial capital investment is necessary, and the treatment scale is limited. Chemical curing technology for dredged sludge derives from traditional soil-curing methods. Mixing cement and other curing agents and inducing stirring, a chemical reaction occurs between the sludge and curing agent, yielding soil with sufficient strength for roads, embankments, and fill material in reclamation projects. The principle of chemical curing technology is that the cement curing material, through a series of water absorption, hydrolysis and hydration reactions, produces gelling substances such as hydrated calcium silicate and hydrated calcium aluminate on the surface of the soil particles of dredged silt, which form an irreversible hardened shell of coagulation on the surface of the soil particles, so as to make dredged silt have a certain degree of water stability and strength stability. In addition, the hydrochemical products with gelling properties form a network structure between the soil particles, which constitutes the skeleton of dredged silt, and some of the crystalline hydrochemical products fill the pores of the network structure, making the internal structure of dredged silt dense, and after the hardening of the gelling substances, the dredged silt will have a certain structural strength. Chemically cured sludge exhibits significantly reduced secondary pollution compared to untreated sludge and demonstrates enhanced environmental stability.[4-6] Chemical curing technology for converting waste dredged mud into renewable resources is widely employed in foreign countries, with this aspect of the technology being relatively mature. Examples include the second runway project at Singapore's "long base" international airport, the dredging and reclamation project at Fushigi Toyama port in Japan, and the foundation improvement project in the Ujina port area of Hiroshima Prefecture. Additionally, several disposal centers for discarded dredged mud in Tokyo, Japan, are capable of selling the treated dredged mud instead of conventional earth and stone materials like sand. Furthermore, they explore the potential of incorporating cement and other materials into dredged mud using chemical curing technology based on mixing piles. The properties and microstructure of silt with the addition of curing agents, such as cement, were investigated.[7–11]

Sintered brick is made of clay, shale, gangue or fly ash as the raw materials, by molding and high-temperature roasting and made for masonry load-bearing and non-load-bearing wall brick, autoclaved brick is in the autoclave and other pressure vessels, steam conservation to improve the early strength of the product of the brick, pressed brick belongs to the non-sintered bricks of a kind of billet through the way of compression, and then through the drying and firing. Silt brick-making represents a novel treatment approach, directly utilizing silt to produce bricks—a method that transforms waste into a valuable resource. Chemically, silt comprises various minerals, predominantly hydrous aluminum silicate, which can be sintered into bricks, ceramics, and other materials.[12,13] Silt represents a novel mineral resource that is available and suitable for large-scale exploitation. Utilizing dredged silt to produce ecological slope protection and landscape blocks tailored to local conditions fulfills the strength requirements, serves as flood control and impact resistance purposes in line with ecological slope protection standards, and addresses silt disposal challenges, mitigating ecological damage. Silt will be utilized to create berms, landscape bricks, or curb blocks, effectively transforming waste into a valuable resource with minimal energy consumption. This approach holds theoretical and practical value for solid-waste valorisation in transportation and water-transport projects.

In pursuit of this goal, this paper presents a method for silt brick-making that eliminates the need for sintering, autoclaving, and pressing. Silt bricks undergo a maintenance period, after which they are examined to assess the impact of cement, initial moisture content, and age on their compressive and flexural strength.

2 EXPERIMENTAL DESIGN

2.1 Test materials

The coastal dredging soil utilized in this study was obtained from Lianyungang City, Jiangsu Province. The sea-phase silt was collected from the vicinity, while the test soil was extracted from the surface layer at a depth of 0–1 m. The physical properties of the silt were assessed following standard procedures. The liquid-plastic limit was determined using a 100-g cone-type liquid-plastic limit tester, the organic matter content was

Table 1: Indicators of basic physical properties of silt

Water content /%	earth (chemistry)	Liquid limit /%	Plastic limit /%	plasticity index	proportion	color	Organic matter content /%
50≈56	CH	57.1	27.5	29.6	2.65	grayish black	1.97

analyzed using the potassium dichromate oxidation method, and the particle analysis was conducted using the densitometer method. The fundamental physical properties of the silt are presented in **Table 1**.

Table 1 reveals that Lianyungang dredged silt exhibits high liquid and plastic limits of 57.1 % and 27.5 %, respectively, with a low organic matter content of 1.97 %, indicating its classification as highly plastic inorganic clay.

2.2 Experimental steps

Considering the range of water content after natural settlement of the silt, dredged mud that does not require dewatering treatment is deemed to maximize the mechanical power and energy savings. The 1× moisture content usually represents the moisture content of the silt in its natural state. This is the base state of the silt and reflects the performance of untreated or processed silt in brick making, while 1.5× moisture content can simulate the state of silt under different humidity conditions by adding moisture. Two groups of dredged silt, each with different water-content states, were selected as raw materials: one with a water content of 1.5× the liquid limit and the other with a water content of 1× the liquid limit. Thus, the silt in its natural water content state needed adjustment to meet the required water content for the test before subsequent testing commenced.

(1) Allocation of sludge with predetermined water content

The dredged soil was initially thoroughly mixed using an electric drill mixer. Subsequently, the original moisture content (w) was determined, and the required amount of water to be added was calculated based on the desired moisture content (w) (1× liquid limit or 1.5× liquid limit). For the test group requiring a small amount of water, tap water was directly added to the active mixer containing silt and mixed until homogeneous, as depicted in **Figure 1**. For the test group requiring a large amount of water, cement, along with external and internal admixtures, was first mixed with water until homogeneous before being added to the active mixer.

Figure 2: Mixed homogeneous material

(2) Mixing

Following the test ratio, a specific quantity of cement and other external and internal admixtures (initially in powdered form, prepared as a solution) was weighed. The cement and external admixtures were added to the total mass of dredged soil (water + solid). Subsequently, all the raw materials were poured in for mixing. To achieve uniform mixing, it was necessary to mix for 30 min, changing the mixing direction every 6 min, as illustrated in **Figure 2**.

(3) Brick making

Brush a layer of mold release agent or oil onto the inner surface of the 240 mm × 120 mm × 53 mm brick mold to facilitate mold release after molding. The material with high water content and in a flowing state is divided into three parts, which are then sequentially filled into the brick mold. After each filling, the mold is placed on a vibration table and vibrated up and down, with each vibration not less than 40 times for the first two times and not less than 30 times for the last time. This ensures that the material is densely packed. Subsequently, the filled mold is placed horizontally to ensure that the upper

Figure 1: Homogeneous specified moisture content soil sample

Figure 3: Loading process

Figure 4: Bricks to be hardened

surface of the brick blanks after molding is level, and the brick blanks are left to harden. **Figure 3** and **Figure 4** depict the loaded material and the brick blanks to be hardened.

(4) Demolding and maintenance

After hardening for 24 h, the brick mold is disassembled by unscrewing four stainless-steel butterfly nuts, withdrawing two long screws, and removing two end plates from the grooves. Subsequently, the molded brick billet is pushed out of the mold. If any brick billet is challenging to remove, the screws connecting the two side plates and the bottom plate can be unscrewed to ensure the integrity of the brick billet during removal. The extracted brick billet is depicted in **Figure 5**. Maintenance is conducted for 7 d, 28 d, and 60 d, as illustrated in **Figure 6**.

2.3 Test methods

The physical and mechanical properties of the dredged silt bricks were tested, encompassing dimensional measurements, bulk density, water absorption, softening coefficient, as well as compressive strength at 7 d and 28 d and flexural strength at 28 d.

(1) Compressive strength

The instrument used for measuring compressive strength is a universal testing machine, with at least one of its upper and lower pressurized plates supported by a ball hinge. The expected maximum destructive load should fall between 20 % to 80 %. In the test method, the specimen is sawed into two brick halves. The stacked part of the two halves of the brick should have a length of not less than 100 mm. If it is less than 100 mm, another spare specimen should be used to compensate. Half of the brick is cut open and soaked in clean water at room temperature for 20–30 min. Afterwards, it is removed and allowed to drip in a wire mesh frame for 20–30 min. Subsequently, it is placed in a sample-making mold in the opposite direction to the fracture, ensuring that the spacing between the two halves of the brick does not exceed 5 mm. The spacing between the brick face and the mold should not be greater than 3 mm, with the mold's internal surface coated with oil or a mold-releasing agent. Next, the slurry material is prepared according to specifications and uniformly mixed in a blender. The specimen mold is placed on a vibration table, and an appropriate amount of well-mixed slurry material is added. The vibration lasts for 0.5–1 min, then cessation until the slurry material reaches its initial solidification time after mold removal. The specimens are then maintained indoors at less than 10 °C for 4 h. Measurements are taken of the length and width of each specimen's connecting or compressed surfaces, respectively. The average values are recorded to the nearest 1 mm as the specimen's length (L) and width (B). Subsequently, the specimen is placed flat in the middle of the pressurized plate, and the load is applied perpendicular to the pressure surface. The loading process should be uniform and smooth, without any impact or vibration, at a 10 mm/min loading speed until the specimen is destroyed. The destructive load (P) is recorded.

(2) Flexural strength

The flexural strength of the silt brick was determined using a universal testing machine with a ball-hinged sup-

Figure 5: Diagram of finished brickwork

Figure 6: Conservation

port for its lower-pressure plate. The expected maximum destructive load falls from 20 % to 80 %. The flexural test involves three-point loading, with the upper pressure roller and the lower support roller having a curvature radius of 15 mm. The lower support roller should be fixed with a hinge. The test method involves using a steel ruler to measure the width and height of the specimen twice, calculating the arithmetic average accurate to 1 mm to obtain the width (*B*) and height (*H*). The flexural fixture under the support roller should be adjusted to span the length of the brick specification minus 40 mm, i.e., 200 mm. The test specimen should be placed on the larger side of the lower support rollers. If the specimen has a crack or dent, it should be positioned so that the crack or dent is at the same distance as the lower support rollers. If the specimen has cracks or depressions, the side with cracks or depressions should face upwards, and a uniform load should be applied at a speed of (50–150) N/s until the specimen breaks. The maximum destructive load (*P*) should be recorded.

3 TEST RESULTS

Dredged sludge with water content at 1.5× and 1.0× the liquid limit had a designed minimum cement admixture of 5 % and a maximum of 17 %, with variations in increments of 4 %. The admixture of cement and gypsum constituted a percentage of the total mass of the sludge (solids + water). Specific experimental mix ratios are detailed in **Table 2**.

Table 2: Mixing ratios of silt bricks

Water content of silt	Cement /%	Gypsum /%
1.5 w_L	10	2
1.5 w_L	15	2
1.5 w_L	5	2
1.5 w_L	20	2
1.0 w_L	20	2
1.0 w_L	15	2
1.0 w_L	10	2
1.0 w_L	5	2

3.1 Stress-strain curve of silt brick

Figure 7 depicts the stress-strain curves for silt bricks at 1.0× and 1.5× the liquid limit. The stress-strain curves for the silt bricks at these two ratios exhibit similar characteristics. As the age increases, the slope of the stress-strain curve increases. However, the growth of the curve for the silt bricks at 1.5× the liquid limit is slower in reaching strain-induced destruction, typically falling within the range 2–3 %. The stress-strain curves display a peak strength, gradually increasing with higher cement doping. This increase in strength is attributed to producing more hydration products, cementitious substances, and crystals, leading to enhanced bonding and skeleton effects within the silt brick structure. Consequently, the compressive modulus of the silt bricks gradually increases.

Under identical strain conditions, silt bricks with higher cement dosages exhibit more excellent pressure resistance. Additionally, with age, the slope of the stress-strain curve increases. However, the strain at which silt-brick failure occurs gradually decreases over time, indicating an enhancement in brittleness as the silt brick ages. This phenomenon is attributed to the primary strength derivation from cement hydration, which has a prolonged reaction period. As the silt brick ages, the degree of hydration and the formation of hydration prod-

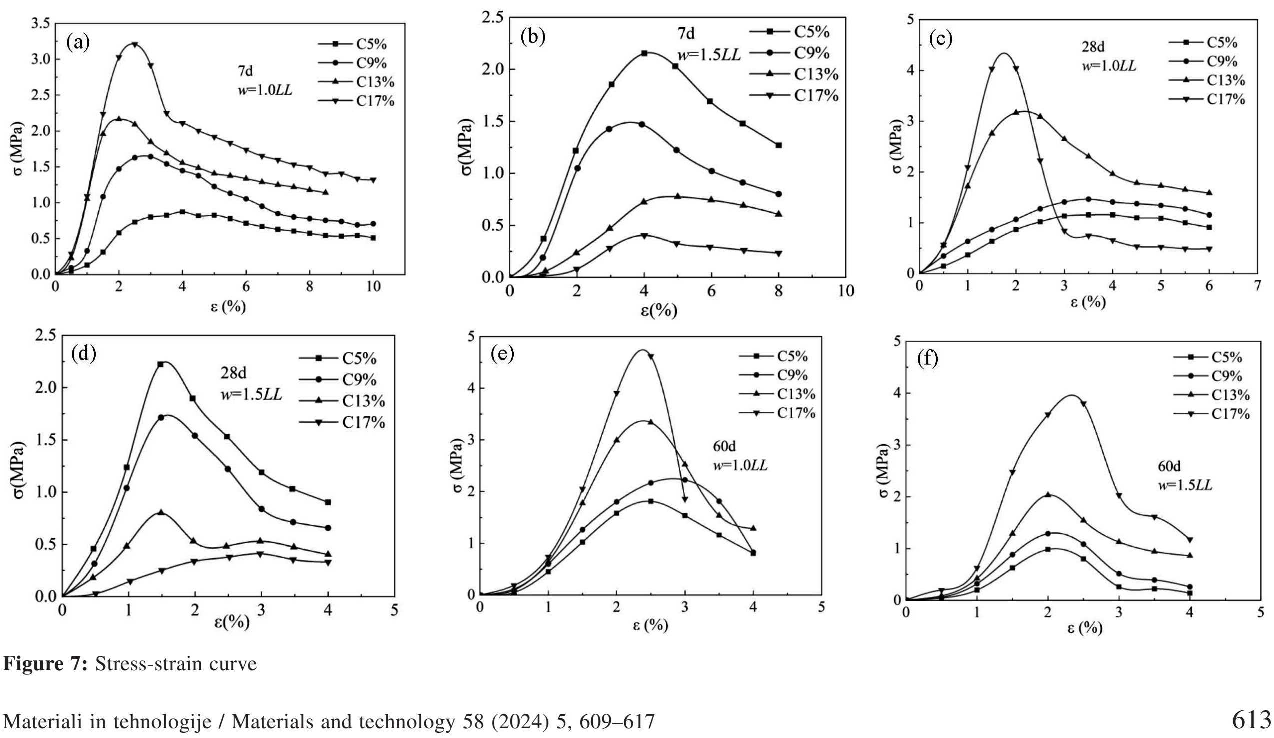

Figure 7: Stress-strain curve

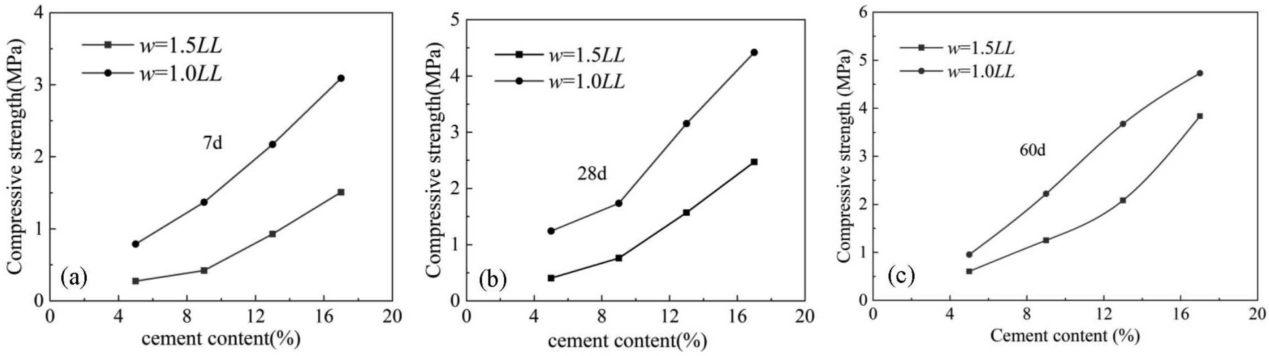

Figure 8: Effect of cement admixture on compressive strength

ucts, crystals, and colloids increase, enhancing the compressive modulus. Nevertheless, in the later stages, this effect diminishes, eventually reaching a plateau.

3.2 Compressive strength of silt brick

(1) Effect of cement dosing on the compressive strength of a silt brick

The compressive strength of dredged silt bricks, fabricated according to the mix ratio specified in **Table 2**, was measured after 7 d and 28 d of curing. To better illustrate the evolution of the silt brick's strength over time, the compressive strength test at 60 d should be included. **Figure 8** presents the results of strength tests at different ages for varying cement-mix proportions.

The figure illustrates that the strength of the silt brick increases linearly with higher cement dosages for all ages. Equation (1) represents the relationship between the compressive strength of the marine-dredged silt brick and the cement dosage. In this equation, q represents the compressive strength, ω denotes the cement dosage, and k and b are test parameters that vary with cement dosage and age.

$$q_u = kw_0 + b \tag{1}$$

The compressive strength of the marine-dredging silt brick mainly arises from the cement hydration process.[14] The primary constituents of cement include tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetra calcium ferro-aluminate. Upon contact with water in the silt, the clinker minerals on its particles' surface promptly initiate a chemical reaction with water, as depicted in equations (2)-(5). During hydration, the calcium silicate produced remains insoluble in water and promptly precipitates as colloidal particles, gradually forming a C-S-H gel. The generated calcium hydroxide (CH) quickly reaches saturation in the solution, precipitating hexagonal plate crystals and cubic crystals of calcium aluminate hydrate. A portion of the saturated calcium hydroxide solution can further react with calcium hydroxide, producing hexagonal tetra-calcium aluminum aluminate hydrate crystals. A small amount of gypsum is mixed to generate a high-sulfur type of calcium aluminate hydrate, namely, calcium alumina. Upon complete gypsum consumption, a portion transforms into mono-sulfur calcium silicate. After completely consuming the gypsum, part transforms into mono sulphur-type calcium thio-aluminate crystals.

The cement-hydration process involves the consumption of water and the release of heat, reducing water content, increasing the volume of the solid phase, fewer pores, and increased strength. Additionally, C-S-H formed during the cement hydration binds fine silt particles together, enhancing the strength. Simultaneously, the process generates calcium hydroxide and alunite crystals, filling voids and providing structural support. As the cement content increases, the coagulation effect intensifies, promoting stronger bonding between the silt particles and forming a denser, more stable structure, thereby increasing the strength of the silt brick.

$$2(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2 \tag{2}$$

$$2(2CaO \cdot SiO_2) + 4H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2 \tag{3}$$

$$3CaO \cdot Al_2O_3 + 6H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O \tag{4}$$

$$4CaO \cdot Al_2O_3 \cdot Fe_2O_3 + 7H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O + CaO \cdot Fe_2O_3 \cdot H_2O \tag{5}$$

Figure 8 illustrates that the compressive-strength-change curve of silt brick with a water content equivalent to 1× the liquid limit, when cement is added, surpasses that of the silt brick with a water content equivalent to 1.5× the liquid limit. This suggests that, under identical cement-dosing conditions, the strength of silt brick with a water content equal to 1× the liquid limit exceeds that of the silt brick with a water content equal to 1.5× the liquid limit. Moreover, the silt-brick strength diminishes with rising water content. This phenomenon arises from the relatively low cement content in the silt, leading to an insufficient cement hydration reaction to utilize all the free water present.[15] Consequently, with a consistent cement mixing ratio, higher silt water content results in more residual water post-cement hydration, creating additional pore space during hardening due to water evaporation and reducing the compressive strength. Conversely, evaporation reduces the pore space when the silt water content is low, enhancing the compactness. The cement hydration-produced gel facilitates easier bonding of the silt particles, forming a cohesive structure. Additionally, the skeleton formed by calcium hydroxide crystals becomes more pronounced.

(2) Effect of age on the compressive strength of a silt brick

Researchers have observed that the strength of a silt brick correlates closely with its age.[16,17] As the specimen's age increases, there is a slight decrease in the compressive strength at optimal temperatures. This enables the billet to attain suitable strength levels in a shorter timeframe, thereby increasing the production efficiency and aligning with the demands of industrialized production. **Figure 9** illustrates the silt brick specimens' compressive strength test results at various ages.

The main constituents of cement clinker include tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium ferroaluminate. Each component exhibits distinct hydration characteristics: tricalcium aluminate hydrates the most rapidly, followed by tricalcium silicate and tricalcium ferroaluminate, while dicalcium silicate hydrates the slowest and dominates the subsequent reaction.

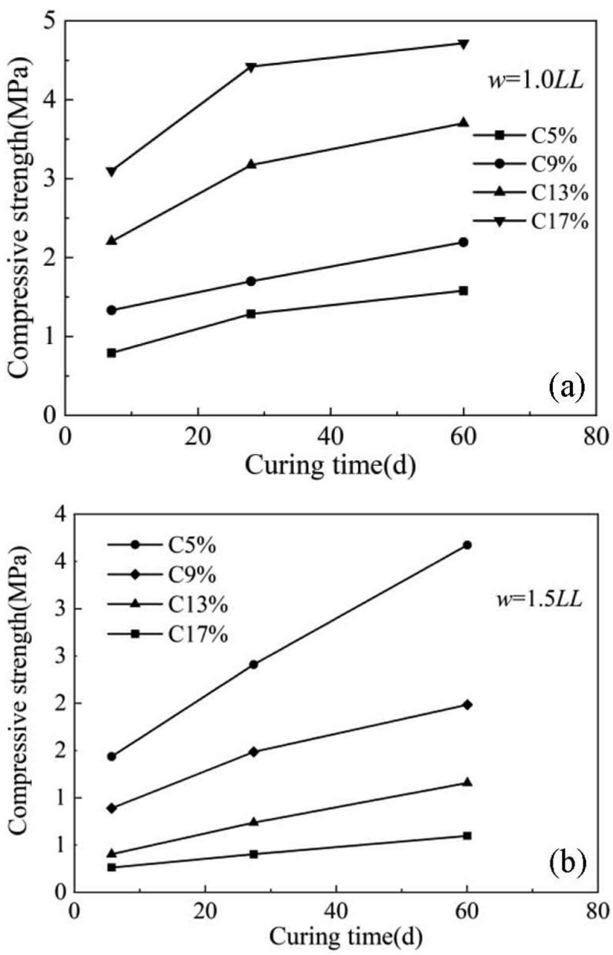

Figure 9: Effect of age on compressive strength of silt brick

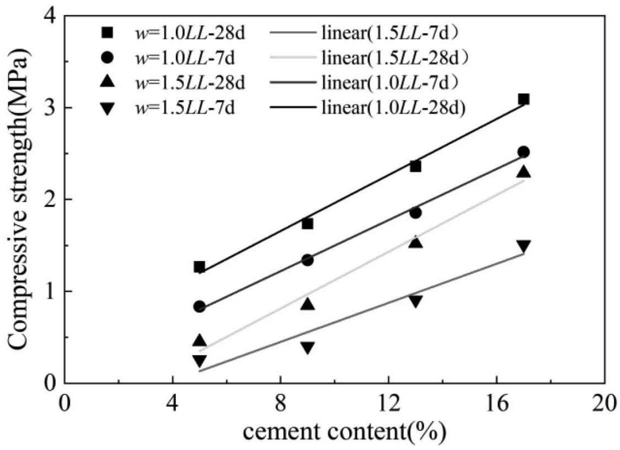

Figure 10: Relationship between cement dosage and peak strength at different ages

Figure 9 illustrates a positive correlation between silt brick's compressive strength and maintenance duration. During cement hydration, a gel-like membrane layer forms initially on the surface, gradually thickening outward. Concurrently, new hydration products deposit within the inner side of this membrane layer. As the hydration reaction progresses, the rate gradually slows, and the thickening of the membrane layer makes hydration inside the cement particles increasingly challenging, albeit still ongoing, prolonging the reaction time. As the maintenance age increases, the cement hydration reaction becomes more extensive. More extended maintenance periods result in more thorough cement hydration reactions, yielding more significant amounts of calcium silicate gel. This gel effectively binds the fine particles in the silt, facilitating the formation of a cohesive skeleton for the silt brick.

The increase in initial water content of the silt at 1.5× the liquid limit exhibited a primarily linear trend with a cement dosing of 17 %. However, the strength growth rate decelerated after 28 d when the initial water content of silt was at 1.0× the liquid limit. When the initial water content of silt is at 1.0× the liquid limit, the strength growth after 28 d is slower than that at 1.5× the liquid limit. This is attributed to a decrease in late-stage water availability when the initial water content is low. Consequently, compared to silt brick with a higher initial water content, the late-stage strength development naturally decelerates. **Figure 10** illustrates the correlation between cement dosing and peak strength at various ages of silt brick.

The effect of cement dosage and peak strength was investigated at an initial water content of 1.0× and 1.5× the liquid limit, at ages 7 d and 28 d, respectively. It was determined through fitting that the results were consistent with equation (1), and the peak strength showed a linear relationship with the cement dosage. The results are as follows and the R2 is not less than 0.94, which is a good fit.

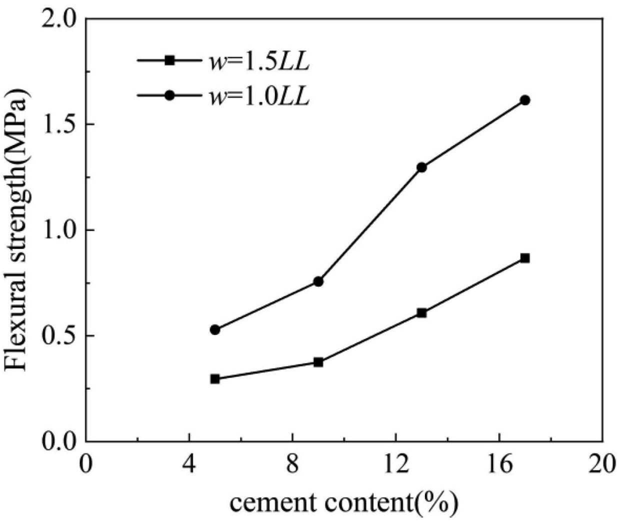

Figure 11: Effect of cement dosing on flexural strength

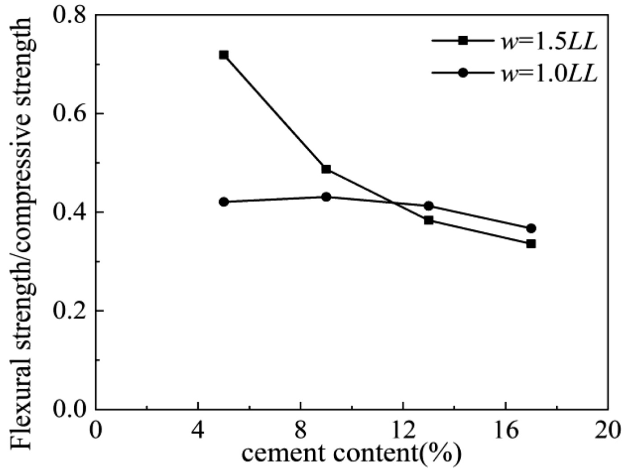

Figure 12: Effect of cement dosing on the ratio of flexural strength to compressive strength

$$1.0\text{LL-7 d:}\quad q_u = 0.10632\, w_0 - 0.39967 \tag{6}$$

$$1.0\text{LL-28 d:}\quad q_u = 0.15451\, w_0 - 0.42224 \tag{7}$$

$$1.5\text{LL-7 d:}\quad q_u = 0.13905\, w_0 + 0.10826 \tag{8}$$

$$1.\text{LL-28 d:}\quad q_u = 0.15248\, w_0 + 0.43762 \tag{9}$$

3.3 Flexural strength of silt brick

Figure 11 depicts the effect of cement dosage on the flexural strength (at age 28 d) of silt brick. It is evident that the flexural strength of the silt brick increases with the increase in cement dosage. Under a condition corresponding to 1.0× the liquid limit, the flexural strength of the silt brick increased from about 0.8 MPa to about 1.3 MPa as the cement dosage increased from 9 % to 13 %, representing a difference of about 0.5 MPa, which was 67.5 % of the flexural strength when the cement dosage was 9 %.

Figure 12 illustrates the variation in the ratio of flexural strength to compressive strength (at age 28 d) with the cement dosage for the same proportion of silt brick. This ratio remains relatively stable, hovering around 0.4, particularly at 1.5× the liquid limit. Notably, the cement dosage of 5 % stands out. The reason may be that cement acts as a binder, and the gel generated by the hydration reaction mainly plays the role of enhancing the overall strength of the bricks, but the enhancement of flexural and compressive strengths of cement is relatively consistent, so its ratio does not change much. Based on the compressive strength of the silt brick, we can estimate its flexural strength.

4 CONCLUSIONS

Numerous dredging and desilting projects are conducted for port and waterway water-transportation and traffic-improvement projects, generating a large amount of dredged mud. Dealing with it quickly and effectively and utilizing it poses a complex problem in engineering. This paper addresses the existing deficiencies in dredging sludge treatment technology and sludge brick-making technology by proposing sintering-free, steam-free, and press-free sludge brick-making ideas. It focuses on selecting Lianyungang marine-dredging sludge and conducting maintenance for a particular age after removing sludge bricks to investigate the impact of cement, initial moisture content, and age on the sludge bricks' compressive strength and flexural strength. The main conclusions of this study are as follows:

(1) Mixing and stirring additive materials with silt, followed by molding, vibration, maintenance, demolding, and further maintenance, demonstrates the feasibility of preparing silt bricks using this process.

(2) Under uniform working conditions, the compressive and flexural strengths of the silt bricks with a water content equal to the liquid limit are higher than those of silt bricks with a water content equal to 1.5× the liquid limit.

(3) The compressive and flexural strengths of silt bricks made by blending cement into marine-dredged silt increased with increased cement blending, showing an approximately linear relationship between them.

(4) The compressive modulus of silt bricks gradually increased with the increase in cement admixture and curing age, resulting in gradually increased brittleness.

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