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Article

Development of Fiber Reinforced Sustainable Dredge Bricks

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Abstract: To maintain adequate depth of commercial waterways, large quantities of earthen material are dredged and stored on undeveloped placement areas adjacent to the waterway. As dredge placement areas become overwhelmed, an environmental and financial sustainable solution for the reuse of dredged soil is prioritized. In this study, locally dredged material from the Sabine-Neches Waterway was used to explore the potential of dredged material in the production of compressed stabilized earth bricks (CSEBs) for small-scale structures in the region. CSEB mixture designs were developed containing fly ash (FA), Portland cement (PC), hydrated lime (HL), water (W), dredged material (DM), and natural and synthetic fibers. Optimized mixtures designs reached the recommended compressive strength of over 1200 psi. Results showed that that the addition of fibers reduced the compressive and flexural strength of the bricks, with a maximum compressive strength of 1394 psi with a corresponding flexural strength of 381 psi being obtained with fiberless dredge bricks. Multiple coating systems were also tested to increase the resistance of the bricks to weathering and erosion. Results showed that the use of coatings reduced water absorption and increased the bricks resistance to erosion, making them more adept in regions commonly subjected to flooding and heavy wind-driven rains.

Keywords: dredged soil; compressed earth bricks; stabilization; compressive strength; erosion resistance

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1. Introduction

Waterways have a constant need to dredge channels for maintenance and must deposit the dredged material (DM) in placement areas making dredge waste management a burden to port and waterway facilities with the potential to restrict expansion capabilities. Waterway management were forced to use placement areas for dredge material storage as bans on ocean dumping became widespread more than twenty years ago causing facilities across the world to try to tackle this societal challenge [1–3]. Placement areas everywhere are over stretched making the management of dredged material a significant problem. Dredged soil has traditionally had very limited practical uses because of its undesirable material properties, however because it is becoming a major concern, the reuse of dredged material has been the object of some investigation by geotechnical and environmental professionals in the industry, none resulting in a cost-effective solution [1–4]. Our research motivation is therefore to find a novel potential commercial use for dredge material instead of simply disposing of the soil in placement areas. The method we report on is based on different suggestions found in the literature.

Using dredge material to produce earth fill has been proposed with some degree of success [3,5], however, another more value-adding possibility is to use dredge material to develop compressed stabilized earth bricks (CSEB). CSEB are easy to manufacture and are relatively uncomplicated to produce in bulk. CSEB can be manufactured using readily available materials and using low energy since they do not need to be fired in a high temperature kiln making them an economically viable alternative in the construction industry. The potential positive impacts for developing viable bricks from dredge material are numerous including the conservation of land that would otherwise be used as a dredge landfill saving taxpayers money and preventing the displacement of local wildlife. In fact, Hamer and Karius report an industrial scale experiment of the fabrication of dredge material bricks [6]. If the dredge CSEB prove to be cheaper than typical concrete masonry units (CMU), a positive implication is the reduction of cement use in local construction projects. In fact, since the cement industry contributes 5% of worldwide emission of CO_2, the use of dredge bricks instead of typical CMUs would greatly benefit the environment because of the reduction in carbon emissions that utilizing less cement entails [7].

The best quality CSEB use soil having optimum compaction and construction properties. In particular, the plasticity index should be between 15 and 30 while the dry unit weight should be within the values of 102 lb/ft^3 and 140 lb/ft^3 [8]. CSEB made from such materials will increase in strength over a period of time, not only because the cementation of the material increases the strength properties, but water evaporation will cause the clay particles to move closer to one another due to an increase in capillary forces. This decrease in water content also increases the modulus of elasticity of the soil along with its compressive strength [9].

Wang et al. studied the most efficient and economical ways to recycle dredged sediment by designing partition blocks. These partition blocks were tested with mixtures of Portland Cement, ground granulated blast-furnace slag, incinerated sewage sludge ash, dredge sediment, and recycled fine and coarse aggregates. Each mixture design contained 20% binder. Compression tests were performed on each mixture and found that after 7 days all mixtures achieved compressive strength of at least 1987 psi, which was well above the standard for partition bricks. The mixture with the highest strength was 16% Portland Cement, 4% ground granulated blast-furnace slag, 16% dredge sediment, 16% fine aggregate, and 48% coarse aggregate [10]. This study suggests that optimization of CSEB may require a variety of stabilizing agents such a Portland cement (PC), fly ash (FA), and lime (L). To create a stabilized dredged material brick with a compression strength greater than 1000 psi while minimizing the use of Portland cement, a recent study found an appropriate combination of Portland cement, hydrated lime, and fly ash with dredged material. After testing the various mixtures, using only 10% by weight of Portland cement was reported to be the optimum ratio, as this mixture reached a compressive strength of approximately 1179 psi [11].

Other studies have identified various types of natural and synthetic fibers that could improve the compressional strength [12–14]. Laborel-Preneron et al. reported on mixtures of polyester fibers of 12 mm in length with soil at relative amounts of fiber ranging from 0–1% and showed that inclusion of polyester fibers increased the strength of the soil until the ratio of fibers added was at 0.5%. After 0.5%, the strength would decrease if any more fibers were added to the soil [12]. Kumar et al. tested the effects of lime, fly ash, and polyester fibers being added to soil. The strength of the soil was tested with 0%, 0.5%, 1%, 1.5%, and 2% of polyester fibers added to it. The results showed that when adding 1.5% of fibers, the tensile strength was 135% greater in comparison with the soil with no fibers. The results for the compressive strength test closely related the results from the tensile strength tests [15].

Park et al. found that poly(vinyl alcohol) (PVA) fibers are another type that can be used in fiber-reinforced concrete. They reported that addition of 1% of PVA fiber and 4% cement sand resulted in two times the increase in strength [16]. Good adhesive properties to cement and high anti-alkali characteristics makes it interesting as a soil reinforcing material.

Other studies found that Kenaf, a natural fiber obtained from the *Hibiscus cannabinus* plant found in Southern Asia, had an absorption of 307%, an elastic modulus of 136 GPa, and a tensile strength of 1000 MPa [12]. The study revealed that the addition of Kenaf improved the flexural strength at higher lengths of fiber while it decreased the thermal conductivity when longer fibers were used within CEB [12]. When fiber content ranging from 0.2% to 0.8% by mass was added, Kenaf was also shown to reduce cracks within CEB improving their mechanical properties and resulting in better building materials than unreinforced blocks for masonry structures [17].

Despite these results, fibers were also found to decrease the compressive strength in CEB making the compressive strength inversely proportional to the fiber content [12]. In addition, the location dependent variations of the soil properties of the dredged material also introduces a unique problem to DM reuse. For dredged material from different waterways, or even from different parts of the same water system, consideration will have to be made in the composition of the soil when utilizing any mixture design. Our team recently tested the stabilization of local dredged materials using a tailored bio-enzyme stabilizer, hydrated lime, quicklime, Portland cement, and fly ash, and found that adding Portland cement increased the strength of the material most dramatically [18]. However, the longevity of a DM stabilization was questioned, hence the need to improve the resistance to erosion in a cost-effective manner. The addition of a coating to CSEB should be considered.

Multiple types of coatings for the purpose of improving the bricks' resistance to weathering and erosion can be studied [19,20]. For example, Eviro-Crete Series 156 produced by Tnemec is a modified waterborne acrylate, typically used for concrete or standard masonry units, that is used to fill in minor hairline cracks and provide protection against driving rainfall. The concentration of Volatile Organic Compounds (VOCs) in the Enviro-Crete measures in at 49 g/liter, significantly lower than the 250 g/liter limitation set by the Environmental Protection Agency (EPA) for exterior coatings [21]. Another example of a commercially available coating is a lime base coating. In this treatment, a base coat utilizes the same clay matter that is used in the production of the bricks, and a finishing coat of a thin layer of hydrated lime is applied which gains strength through the creation of Calcium Silicates Hydrates (CSH) bonds from its reaction with water. As it cures, calcium hydroxide reacts with carbon dioxide to form calcium carbonate and water [22]. This ability for lime to react with carbon dioxide allows for free lime to selfheal cracks.

Our objective is to find an environmentally and economically friendly use for dredged material in order to reduce or completely eliminate the use of dredge landfills. Building on previous work, the viability and reliability of CSEB was evaluated by developing stabilized dredged bricks composed of dredge material (DM), fly ash (FA), Portland cement (PC), lime (L) and natural and synthetic fibers to evaluate the changes in strength properties and resistance to erosion of the bricks.

2. Materials and Methods

2.1. Sample Collection

Dredge material was locally sourced from the Sabine-Neches Waterway in Texas, USA. This dredge was collected from Placement Area 9, shown in Figure 1, along the Sabine-Neches Waterway and stored in multiple 5-gallon buckets. Prior to any testing or mixing, samples were completely dried in an oven held at 200 °C for about seven days. Samples were subsequently pulverizedbefore testing or brick fabrication.

2.2. Dredge Material Property Test

Before fabricating the bricks, the DM was tested for consistency. Several analytical tests were performed on the dredge material and compared to previous analysis of materials from the same placement area. Specific gravity, Proctor compaction test, organic content test, Atterberg limits tests, along with grain size analysis was performed. The specific gravity of the dredge material is a critical part in determining the weight and volume relationships in the mix design process. The specific gravity was determined in accordance with ASTM D854 standards. A second analysis determined the optimum moisture content for the maximum dry density by using the Proctor compaction Test following ASTM D698 standards. An organic content test was performed in accordance with ASTM D2974 to find the percentage of organics within the dredged material. This information was needed to ensure that the reactions that occur during cementation will not be impeded by an excess amount of organics. The liquid and plastic limits of the dredge material were found in order to classify the dredge material. This testing was done following ASTM D4318 guidelines. Finally, the grain size distribution was evaluated to help classify the dredge material. A standard minus 200 test was used in order to determine the amount of material that passes the #200 sieve. This test was performed by following the standards listed in ASTM D1140. A hydrometer test was also performed in order to measure the grain size analysis of particles that pass through the #200 sieve. This test was done in accordance with ASTM D422 standards.

Figure 1. Sabine-Neches Waterway Placement Area 9 (Latitude: 29.82821, Longitude: −93.97543) [23].

2.3. Brick Mixture Combinations

Different mixture combinations were developed using the information gathered from the previous research and dredge material testing. These combinations were used to fabricate bricks with consistent dimensions in order to test the compressive and flexural strength along with the absorption and erosion properties of each mix. Compressive strength testing and erosion testing were performed to evaluate the effectiveness of each fiber used. Each brick was based upon the previously researched mix design using 10% PC with 35 parts hydrated lime and 80.5 parts fly ash as a percent, based on 100 g of dredge material [11] with the inclusion of fibers. Based on the rate of success reported in the literature, three types of fibers were selected, PVA, polyester and kenaf.

2.4. Mixing Dredged Materials with Agents

As previously mentioned, the mixture design developed by our previous work and containing 10% cement, was utilized in the creation of the bricks used for this study. Traditionally, the mixing process was done in a standard stand-mixer. For more homogenous mixing, the materials were batched in a 5-gallon bucket and mixed using a power drill equipped with a mixing bit. This mixing method generated larger batches and reduced the mixing time.

2.5. Equipment for Dredge Brick Production

An Impact 2001A press was used to produce the CSEB. This hydraulic brick press weighs 640 pounds, and measure 81 inches long by 68 inches wide by 51 inches high. Its power is generated by a 7.0 HP Yanmar diesel engine. This press is equipment with Worldwide hydraulics and has 19.5-gallon tank capacity. The hopper capacity is 8–9 Blocks, depending on block thickness. The production rate is approximately 300 blocks per hour, or equivalently 5 bricks per minute. Following the completion of the brick making process, the bricks were cured while air dried to allow for the water to evaporate and cause suction between the clay particles [9].

2.6. Brick Property Tests

Once the bricks had cured under room temperature, unconfined compression tests were performed to determine the compressive strength of each mix. Each brick was tested after curing periods of 7 and 28 days. In addition to the compression testing a flexural strength test was performed after 28 days in order to test the fibers effectiveness in tension. The absorption properties of each brick were tested in accordance with ASTM C140 standards and the resistance to erosion was also tested. However, since there is currently no ASTM testing procedure for this, a modified version of the bulletin 5 spray test [24] was used to measure the bricks resistance to erosion. The required erosion spray parameters were determined determining kinetic energy from the local annual rainfall.

2.7. Control Coatings to Minimize Erosion

Since bricks composed of soils are highly susceptible to erosion, coating systems were compared to evaluate absorption of the bricks and increase the resistance to erosion. Two commercially available and regularly used coatings were selected because of their use in the regional industry: Enviro-Crete series 156, and a lime stabilized sand mortar.

3. Results and Discussion

3.1. Soil Characteristics and Classification

The first step in classifying the type of dredged soil involves the minus 200 wash which showed that only 3.1% of the material was retained on the No. 200 sieve. Therefore, 96.9% of the dredge material was either clay or silt. A hydrometer test revealed that of the material passing the #200 sieve, approximately 37% was clay and 63% was silt while a separate organic content test demonstrated that dredged soil contained 5.4% organic matter.

To evaluate the optimum moisture content of the samples a standard Proctor test was performed which revealed that an optimum moisture content of 19.7% would yield a maximum dry density of approximately 91.9 $\mathrm{lb/ft^3}$. The specific gravity of the soil was determined to have a relatively low value of 2.27. Finally, Atterberg Limit tests were performed, from which we concluded that the dredged material could be classified as a fat clay (CH) with a relatively high plastic index (PI) of 46.

3.2. Brick Mechanical Tests

Two mechanical strength tests were performed on the untreated bricks and those mixed with different fibers. Unconfined compressive strength (UCS) tests were first performed to evaluate the overall strength of the bricks followed by 3-point bending moment tests on samples cured for 28 days to confirm the UCS tests and determine the effect of the inclusion of fibers on the flexural strength of the bricks.

Table 1 compares the strength test results for the bricks containing different types of fiber and ratios of fiber inclusion. UCS tests were performed 7 and 28 days after brick fabrication while the 3-point bending moment tests were performed on 28 days old bricks only. Strength tests show that unconfined compressive strength of the proposed mixture designs at 7 and 28 days, respectively, was 1070 psi and 1394 psi with a flexural strength of 381 psi. The New Mexico code [25], states that the average compressive strength of a brick shall be a minimum of 300 psi. The proposed mix design used in this study appears to meet the requirements. Increasing the brick age from 7 to 28 days led to an increase in UCS between 30 and 60%. Adding fibers resulted in a decrease in UCS and in flexural strength. The addition of PVA, regardless of amount, caused significant decreases in mechanical strength while the addition of polyester or kenaf fibers caused only moderate decreases. This result supports the findings of Gowda that the increase in fibers inversely affects the compressive strength of the bricks [26]. It can be noted however, that even with lower flexural strengths, the bricks with fiber inclusion failed after a longer loading period than bricks without fibers. To better understand the cause of the effect of the fibers on the mechanical properties of the bricks, scanning electron microscopy was used to determine the interactions, if any between the soil and fibers.

Table 1. Comparison of the strength tests for CSEB containing different fiber inclusions.

Fiber	Application Rate (%)	7-Day UCS	28-Day UCS	Flexural Strength
None	-	1070	1394	381
PVA	0.25	724	907	201
	0.50	354	666	108
	0.75	240	497	108
Polyester	0.05	740	1123	195
Kenaf	0.10	872	1151	260

3.3. SEM Images

Scanning electron microscopy (SEM) images were taken on four specimens, each containing different fibers, to obtain visual representation of the bonding of cementitious material and fibers. Figure 2 shows the typical images of the inside of a fabricated brick without fibers (panel A), with PVA fibers (panel B), with polyester fibers (panel C) and with kenaf fibers (panel D). The bricks without fibers show that the DM particles and additives, following a series of chemical reactions known as pozzolanic reactions, have merged together to form a denser and grainy structure known as cementation. Cementation refers to the pozzolanic reactions between calcium hydroxide (from lime, cement, and fly ash) and oxides broken down from the clay minerals such as silica and alumina [27]. The presence of calcium hydroxide provides a high-pH environment which is crucial for the completion of pozzolanic reactions [28]. Since fly ash requires an extended period of time to completely react, visible lumps of fly ash (sphere particles) can be observed in panel A confirming our previous report [29]. When adding PVA, the fibers do not interact with the soil but separate and assemble with each other more, which produces larger voids/gaps between the PVA and the stabilized DM. This results in large defects in the structure without proper inter-bonding between the fibers and the stabilized DM which leads to significantly lower mechanical properties as shown in Table 1. When added to the soil material, fibers of either polyester of kenaf disperse more readily throughout resulting in a more homogenous material. However, while the sample seems more closely packed, the presence of the fibers may act as mechanical defects causing some decrease in the mechanical strength. As discussed previously, this disadvantage may be compensated by an increase in the resistance to erosion of the bricks.

3.4. Erosion Tests

To evaluate the effect of erosion on the bricks, two tests were performed. A control test consisting of a 24 h percent absorption following ASTM C140 and an erosion from rainfall simulation test. The absorption test was performed on bricks without coating and with two coatings used in the industry, i.e., Enviro-Crete and lime-sand mortar. Figure 3 presents the results of the absorption test for these three samples. The percentage absorption is defined as 100 × (saturated weight-oven dry weight)/oven dry weight. As shown in the figure, uncoated bricks have significant absorption of about 13.6% while the lime stabilized sand coated was somewhat better with an absorption of 9.4%. The Enviro-Crete performed significantly better with an absorption of only 0.8%. Although the brick coated with lime stabilized sand shows better performance with 31% improvement than the brick without coating, the high absorption rate of 9.4% is not expected and it is still much higher than the maximum of 2.5% requirement. The high absorption rate of the brick coated with lime stabilized sand may be due to lacking good bonding between the coating and the brick surface and therefore, forming uneven shrinkage and tiny hairline cracks in the surface during the curing process. With these results in mind the erosion from rainfall simulation test was performed on bricks with different types of fibers.

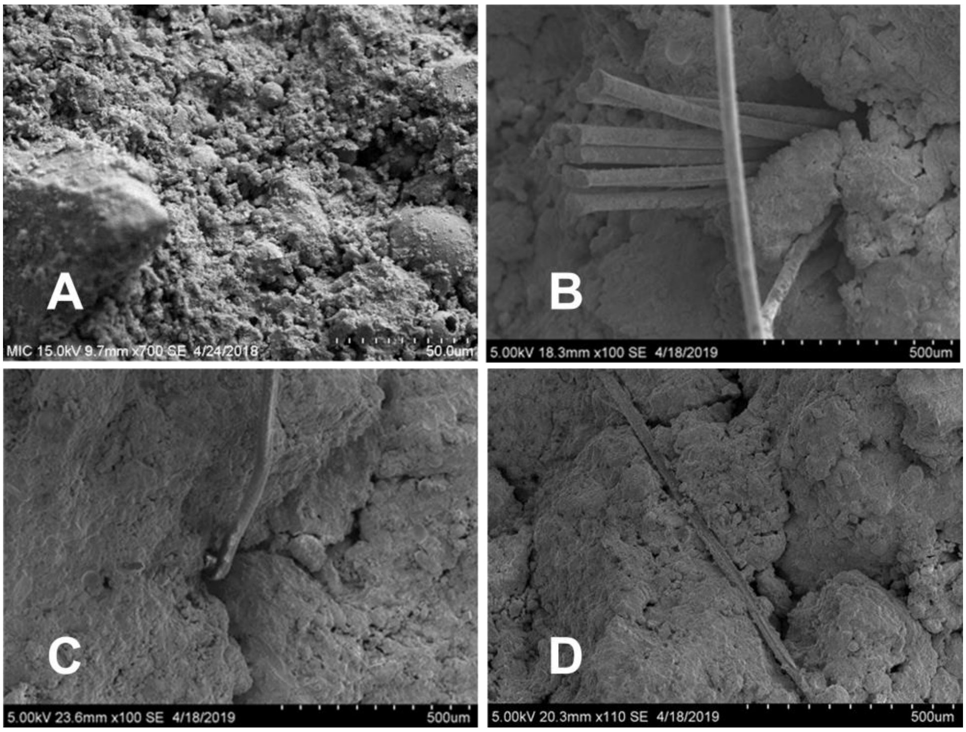

Figure 2. SEM images of four types of CSEB: without fibers (**A**), with PVA (**B**), with polyester (**C**) and with kenaf fibers (**D**).

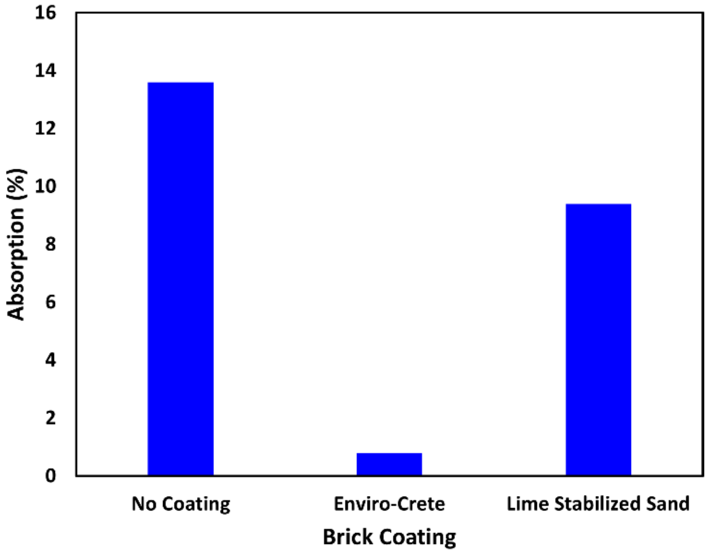

Figure 3. Water absorption tests of uncoated and coated bricks.

3.5. Rainfall Simulation Tests

The rainfall simulation test consisted in spraying a quantity of water on the material's surface and measuring the amount of wear. Figure 4 illustrates the erosion testing using a custom designed rig. To simulate erosion from rainfall, the erosion testing time was determined by estimating the kinetic energy produced by the annual rainfall in the Beaumont, Texas, USA area and generating the same kinetic energy using water exiting the nozzle on the erosion rig. The National Oceanic and Atmospheric Administration (NOAA) estimated that the average annual rainfall of Beaumont, TX was 60 inches [30]. The kinetic energy of annual rainfall was calculated using the equation: Ek = K × Pa, with K = 24 J/m^2/mm. The equivalent kinetic energy of annual rainfall was found to be 36.6 kJ/m^2. Based on industrial recommendations regarding external surface wear, a 15-year life span was chosen that included a 150% safety factor. The Bernoulli's equation was used to determine the velocity of the water leaving the nozzle and using this value and that of the calculated kinetic energy, the mass of water needed was calculated using the equation: $Ek = \frac{1}{2}\,mv^2$. The solved mass was divided by the unit weight to find a total volume, and this was divided by the measured flow rate to time of spraying. The flow from the nozzle was adjusted and the previous steps were repeated until the required spray time was 3 h.

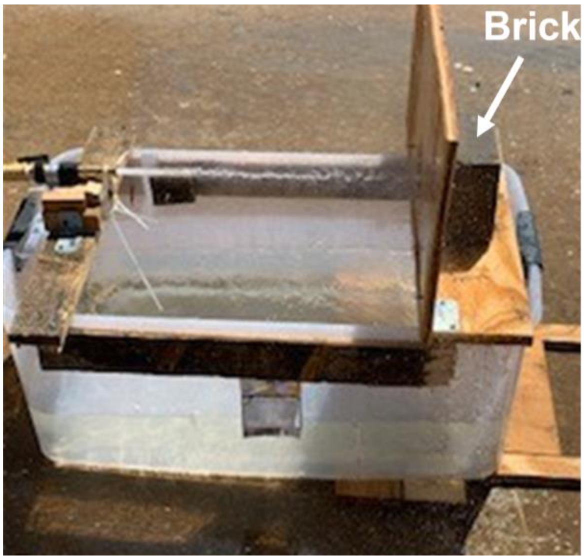

Figure 4. Modified Water Erosion setup. A specific flow of water impacts the brick for three hours simulating 15 years of rainfall erosion.

After spraying, the deepest indentations in the bricks were measured and a dry post-erosion weight was measured to evaluate material loss. This erosion test was performed at three-hour intervals on three bricks for CSEB without the inclusion of fibers, uncoated, and coated. Following the erosion test, each brick was oven dried for 36 h at 200 °C and air dried for another 48 h to bring each brick to its pre-test moisture level. We note that since Enviro-Crete coated brick were uncoated on one side, the moisture did not evaporate at the same rate as it did with others. The erosion testing was then repeated on uncoated bricks that contained fibers. Figure 5 shows images of the bricks following the erosion test. The control represents uncoated bricks before and after the test. Numerous indentations can be observed. When uncoated bricks were mixed with fibers, some indentations are also clearly visible. In particular the samples containing PVA eroded more which is probably the result of larger voids/gaps between PVA and the stabilized DM that were observed in Figure 2B and associated with lower USC strength as reported in Table 1. The bricks containing either polyester or kenaf fibers seem to have experienced smaller but more numerous indentations which is expected and consistent with the USC strength as shown in Table 1. To quantify the effect, the average size of the indentations and of the change of mass following the test were measured and are reported in Table 2.

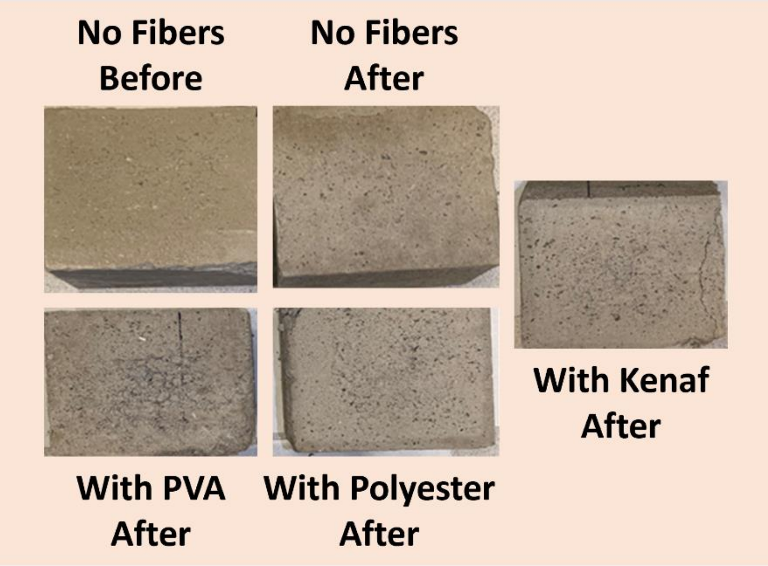

Figure 5. CSEB before and after erosion test.

Table 2. Results from erosion test on uncoated and coated bricks.

Brick	Average Pit Depth (mm)	Maximum Pit Depth (mm)	Mass Before Spray Test (lb)	Mass after Spray Test (lb)	Mass Loss (lb)	Mass Loss (%)
No Coating/No Fiber	3.1	5.0	7.061	6.952	0.109	1.544
Enviro-Crete	0.0	0.0	6.840	6.916	−0.076	−1.111
Lime-Sand Mortar	N/A	N/A	N/A	N/A	N/A	N/A
No Coating/Kenaf Fiber	2.1	3.3	6.534	6.344	0.190	2.908
No Coating/PVA Fiber	7.2	10.0	5.617	5.357	0.260	4.629
No Coating/Polyester Fiber	2.2	2.8	6.582	6.378	0.204	3.099

The data for the lime-sand mortar coating is not reported because the coating failed. The lime-sand mortar coating failed within 15 min of the spray test most likely because of a lack of bonding between the coating and the brick surface as discussed earlier for higher-than-expected water absorption. For optimal application this coating requires a greater sand and cement ratio as opposed to the more clayey soil of the dredge material. Table 2 indicates that bricks with no coating/PVA fiber have the highest maximum pit depth and mass loss, followed by bricks with no coating/kenaf and polyester fibers which share similar results, followed by bricks with no coating/no fiber, and finally bricks with the Enviro-Crete coating. The values reported in Table 2 confirm the visual observations that bricks with the Enviro-Crete coating had a significant resistance to erosion compared to uncoated bricks. We note that the mass of the brick coated with Enviro-Crete increased during the test, probably because of water absorption on the uncoated, top surface of the brick. Of more interest is the impact of fibers of polyester and kenaf on resistance to erosion. The bricks containing either of these fibers had more shallow indentations and less average pit depth than that of the uncoated bricks. However, their mass loss was about twice that of regular bricks. This suggests that the presence of these fibers could help distribute the load and hence reduce damage from weathering if fibers/soils can be mixed thoroughly.

4. Conclusions

In an effort to alleviate the burden placed on ports and waterways in managing dredged waste, we explored the potential of utilizing dredged material as the principal component in the production of compressed stabilized earth bricks. Dredge material was mixed in different compositions with classic stabilizing agents such as Portland cement, hydrated lime, and synthetic and natural fibers. The novelty of our approach is the possibility of using about 80% DM in the brick composition. Strength tests showed that the unconfined compressive strength of the proposed mixed design at 7 and 28 days, respectively, was 1070 psi and 1394 psi which meet the minimum strength requirement of 300 psi by the New Mexico Code for compressed earth block production. The strength behavior was negatively impacted by the addition of any type of fibers although fibers of polyester and kenaf did not significantly decrease the flexural strength of the bricks. Erosion tests revealed that these two types of fiber could help reduce damage from weathering if mixed thoroughly. Uncoated bricks have significant absorption of about 13.6% while the lime stabilized sand coated was somewhat better with an absorption of 9.4%. The Enviro-Crete performed significantly better with an absorption of only 0.8%. Only bricks with Enviro-Crete coating meet the maximum of 2.5% requirement. Erosion test results also show no indentation (zero pit depth) for bricks with Enviro-Crete coating.

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References

1. Maher, A.; Douglas, W.S.; Jafari, F. Field placement and evaluation of stabilized dredged material from New York New Jersey Harbor. *Mar. GeoResour. Geotechnol.* **2006**, *24*, 251–263. [CrossRef]
2. Brils, J.; de Boer, P.; Mulder, J.; de Boer, E. Reuse of dredged material as a way to tackle societal challenges. *J. Soils Sediments* **2014**, *14*, 1638–1641. [CrossRef]
3. Cevikbilen, G.; Basar, H.M.; Karadogan, U.; Teymur, B.; Dagli, S.; Tolun, L. Assessment of the use of dredged marine materials in sanitary landfills: A case study from the Marmara sea. *Waste Manag.* **2020**, *113*, 70–79. [CrossRef] [PubMed]
4. Jamsawang, P.; Charoensil, S.; Namjan, T.; Jongpradist, P.; Likitlersuang, S. Mechanical and microstructural properties of dredged sediments treated with cement and fly ash for use as road materials. *Road Mat. Pavement Design* **2021**, *22*, 2498–2522. [CrossRef]
5. Li, M.D.; Cong, X.; Zhu, L.P.; Kong, L.P.; Zhang, Z.F.; Tian, A.G.; Li, L. Experimental study on recycling dredged marine sediment and phosphate tailing to produce earth fill. *Mar. GeoResour. Geotechnol.* **2017**, *35*, 586–591. [CrossRef]
6. Hamer, K.; Karius, V. Brick production with dredged harbour sediments. An industrial-scale experiment. *Waste Manag.* **2002**, *22*, 521–530. [CrossRef] [PubMed]
7. Rubenstein, M. Emissions from the Cement Industry. State of the Planet. 2012. Available online: https://news.climate.columbia.edu/2012/05/09/emissions-from-the-cement-industry/ (accessed on 12 December 2022).
8. Grubb, D.G.; Chrysochoou, M.; Smith, C.J.; Malasavage, N.E. Stabilized Dredged Material. I: Parametric Study. *J. Geotech. Geoenviron. Eng.* **2010**, *136*, 1011–1024. [CrossRef]
9. Serbah, B.; Abou-Bekr, N.; Bouchemella, S.; Eid, J.; Taibi, S. Dredged Sediments Valorisation in Compressed Earth Blocks: Suction and Water Content Effect on Their Mechanical Properties. *Constr. Build. Mater.* **2018**, *158*, 503–515. [CrossRef]
10. Wang, L.; Chen, L.; Tsang, D.C.W.; Li, S.J.; Baek, K.; Hou, D.; Ding, S.; Poon, C.S. Recycling Dredged Sediment into Fill Materials, Partition Blocks, and Paving Blocks: Technical and Economic Assessment. *J. Clean. Prod.* **2018**, *199*, 69–76. [CrossRef]
11. Johnson, R.; Bonner, B.; Fernande, D.; Aleman, F.; Defrancis, J. *Dredged Stone Erosion Mitigation. Final Report*; Lamar University: Beaumont, TX, USA, 2018.
12. Laborel-Preneron, A.; Aubert, J.E.; Magniont, C.; Tribout, C.; Bertron, A. Plant Aggregates and Fibers in Earth Construction Materials: A Review. *Constr. Build. Mater.* **2016**, *111*, 719–734. [CrossRef]

13. Hussain, M.; Levacher, D.; Saouti, L.; Leblanc, N.; Zmamou, H.; Djeran-Maigre, I.; Razakamanantsoa, A. Implementation on a Preparation and Controlled Compaction Procedure for Waste-Fiber-Reinforced Raw Earth Samples. *J. Compos. Sci.* **2022**, *6*, 3. [CrossRef]
14. Han, H.; Ju, C.G.; Yan, W.Z.; Yang, M.; Wan, Q.Q.; Li, Q.Q.; Wu, Y. Performance improvement of non-sintering permeable brick with the addition of fibers at a low content. *J. Build. Eng.* **2021**, *43*, 103191. [CrossRef]
15. Kumar, A.; Walia, B.A.; Bajaj, A. Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. *J. Mater. Civ. Eng.* **2007**, *19*, 242–248. [CrossRef]
16. Park, S. Effect of Fiber Reinforcement and Distribution on Confined Compressive Strength of Fiber-Reinforced Cemented Sand. *Geotext. Geomembr.* **2009**, *27*, 162–166. [CrossRef]
17. Millogo, Y.; Aubert, J.M.; Hamard, E.; Morel, J.C. How Properties of Kenaf Fibers from Burkina Faso Contribute to the Reinforcement of Earth Blocks. *Materials* **2015**, *8*, 2332–2345. [CrossRef]
18. Nguyen, T.T.M.; Rabbanifar, S.; Brake, N.A.; Qian, Q.; Kibodeaux, K.; Crochet, H.E.; Oruji, S.; Whitt, R.; Farrow, J.; Belaire, B.; et al. Stabilization of Silty Clayey Dredged Material. *J. Mater. Civ. Eng.* **2018**, *30*, 04018199. [CrossRef]
19. Treloar, G.J.; Owen, C.; Fay, R. Environmental assessment of rammed earth construction systems. *Struct. Surv.* **2001**, *19*, 99–106. [CrossRef]
20. Liu, S.; Gao, X. Evaluation of the Anti-Erosion Characteristics of an MICP Coating on the Surface of Tabia. *J. Mater. Civ. Eng.* **2020**, *32*, 04020304. [CrossRef]
21. Environmental Protection Agency. Architectural Coating Rule for Volatile Organic Compounds. Available online: https://www.epa.gov/sites/production/files/2015-11/documents/aim_coatings_detailed_factsheet.pdf (accessed on 12 December 2022).
22. Webb, P. Natural Hydraulic Limes: A Plaster in a League of Its Own. Traditional Building. 2016. Available online: https://www.traditionalbuilding.com/opinions/natural-hydraulic-limes-plaster-league (accessed on 12 December 2022).
23. Google Map Image (Latitude: 29.82821, Longitude: −93.97543). Available online: https://www.google.com/maps/place/29%C2%B049\T1\textquoteright41.6%22N+93%C2%B058\T1\textquoteright31.6%22W/@29.8296707,-93.9826311,3432m/data=!3m1!1e3!4m5!3m4!1s0x0:0x7082890fe16d0369!8m2!3d29.82821!4d-93.97543!5m1!1e8 (accessed on 12 December 2022).
24. Obonyo, E.; Exelbirt, J.; Baskaran, M. Durability of compressed earth bricks: Assessing erosion resistance using the modified spray testing. *Sustainability* **2010**, *2*, 3639–3649. [CrossRef]
25. New Mexico Earthen Building Materials Code. Construction Industries Division of the Regulation and Licensing Department. Title 14: Housing and Construction Chapter 7: Building Codes General. 2009. Available online: http://www.udcinc.org/2009%20New%20Mexico%20Earthen%20Building%20Materials%20Code.pdf (accessed on 12 December 2022).
26. Gowda, R.P.C. Experimental Study of Cement Stabilized Fiber Reinforced Compressed Earth Blocks as an Alternative Building Material. Master's Thesis, Arizona State University, Tempe, AZ, USA, 2016; pp. 10–127.
27. Milburn, J.; Parsons, R. Performance of Soil Stabilization Agents. Univ. of Kansas and Kansas Dept. of Transportation. 2004. Available online: https://rosap.ntl.bts.gov/view/dot/38749 (accessed on 12 December 2022).
28. Mitchell, J.K.; Soga, K. *Fundamentals of Soil Behavior*; Wiley: New York, NY, USA, 2005.
29. Rabbanifar, S.; Nguyen, T.T.M.; Yao, C.W.; Qian, Q.; Bernazzani, P.; Jao, M. Adding Value to Dredged Material Using Lime and Ash Products. In Proceedings of the Recent Trends in Geotechnical Geo-Environmental Engineering and Education RTG2EE International Conference, Online, 10–11 September 2020; pp. 94–98, ISBN-13: 978-0-6489449-0-4.
30. NOAA 2019. Climate Information, NOAA's National Weather Service, 2 January 2019. Available online: https://www.weather.gov/lch/bptclimategraphs (accessed on 12 December 2022).