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Stabilised compressed earth bricks made with coastal solonchak

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HIGHLIGHTS

- Using saline soil to produce stabilised compressed earth brick (SCEB) was studied.
- The solonchak collected along the coastal area of Tianjin, China was characterised.
- Activation pretreatment was applied to enhance the pozzolanic activity of the soil.
- The SCEB with activated soil has much improved strength and water resistance.
- The environmental impact of the produced SCEB was evaluated.

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ABSTRACT

This paper presents a study on the production of stabilised compressed earth brick (SCEB) using coastal solonchak. The solonchak collected along the coastal area of Tianjin, China was characterised. With activation pretreatment, the pozzolanic activity of the saline soil was significantly enhanced and the SCEB with high strength and water resistance has been produced. Three chemical additives, i.e. sodium silicate, hydrofluoric acid and phosphoric acid were used in the activation pretreatment. The results indicated all of these have the effects to enhance the pozzolanic activity of the saline soil with lime and Portland cement and phosphoric acid gave the best results in terms of the activity index test. SCEB was then produced with activation pretreated saline soil, lime, Portland cement and sand with pressure moulding and standard curing. The mixes with 50% activated saline soil obtained 28 day compressive strength 28–55% higher and water resistance 44–66% higher than the reference mix using untreated saline soil, with more effective at low PC content. The study also revealed that the produced SCEB could be degraded back to soil for plantation after demolish and long term weathering. This study thus provided prospective environmentally friendly masonry units for sustainable construction.

1. Introduction

Solonchaks, also called 'saline soils' or 'salt-affected soils', are soils that have a high concentration of 'soluble salts', which are mainly found in the arid/semi-arid climatic areas and coastal regions. Solonchaks are widespread in northern Africa, the Middle East, central Asia, Australia and the Americas, having limited potential for cultivation of salt-tolerant crops and most of them are not used for agriculture at all [1]. While the study of the agriculture researchers focused on the solonchak vegetation [2], the study of the civil engineers was mainly on its stabilisation in situ for infrastructure constructions [3] and coastal soil treated with cement to improve unconfined compression strength was reported [4]. However, no report was found about the use of solonchak in the production of building materials such as stabilised compressed earth bricks/blocks (SCEB).

With China's rapid construction development, there is a large demand for building materials, which brings about serious environmental problems simultaneously. As reported [5], in China the annual output of Chinese standard brick is about 800 billion pieces, consuming up to 60 million tonnes of coal and destroying more than 1.5 million mus (247,105 acres) of farmland. The use of solonchak to produce SCEB utilises uncultivable soil thus provides a way to mitigate the farmland destruction and reduce non-renewable resources consumption. The use of poor quality soils and other solid industry wastes in the production of SCEB was also recently reported by Siqueira and Holanda [6].

SCEB [7–9] are manufactured by mixing earth (i.e. soil without organic content, generally subsoil with some clay content [10]) with the stabilisers such as cement and/or lime and then forming

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the brick or block shape by compaction. In the current European standard BS EN 771-3:2011 [11], there are no standard product sizes given and the distinction between brick and block has been removed. SCEB has different names in the literature, such as 'Soil–cement bricks/blocks' [12–14], 'Stabilised soil blocks' [15,16] or 'Unfired clay bricks' [17,18].

The use of SCEB can be traced back more than 50 years [19,20]. Early attempts were made to develop the material as an alternative walling unit to the costly fired bricks and concrete blocks, promoted by the United Nations. Although the idea of compacting earth to improve its quality and performance in the form of moulded blocks could be dated back to the 18th Century [21] the addition of a binder to stabilise the soil is more recent. Following the declaration of the year 1987 as the 'International Year of Shelter for the Homeless (UN/IYSH, 1987)', SCEB products developed rapidly mainly in the developing countries including China, India and a number of African and South American countries [7,21–26], part of them with the technical collaboration from the developed countries. The recent momentum of the promotion of SCEB is driven by the sustainable construction considerations since its production has no firing process. Its environmental benefits include reduced energy consumption and CO_2 emission in production and a lessening demand for non-renewable resources [7,18,27]. Widespread application of SCEB is found around the world including the UK and a number of developed countries [9,14,18,27–31].

The properties for SCEB from literature are quite wideranging, varying from country to country and from author to author. Some produced the SCEB with the wet compressive strength (i.e. water saturated strength) around 1–9 MPa [6,7,13,23,29,32–39] to meet the minimum requirements for rammed earth construction that $\geqslant$1.2 MPa is widely used [15,21]. Others produced the SCEB with higher strength ranging from 5 MPa to 40 MPa [8,14,16,25–27,30,40–43] to comply with the requirements for fired clay bricks or concrete masonry units. In this study, the SCEB samples incorporating coastal solonchak were prepared with the strength ranging within the requirements of current Chinese solid concrete brick standard GB/T 21144-2007 [44] which specified six strength grades from 15 MPa (MU15) to 40 MPa (MU40). The solonchak collected along the coastal area of Tianjin, China was characterised. With activation pretreatment, the pozzolanic activity of the saline soil was significantly enhanced and the SCEB with high strength and water resistance has been produced, which provided environmentally friendly masonry units for sustainable construction.

2. Characterisation of the coastal solonchak

The solonchak was collected along the coastal area of Tianjin, China. A total of 5 saline soil samples were obtained with the different distances from the coastal line (Table 1). The samples were taken from the undisturbed layer under the surface. Stones and plant residues were removed before it was sealed in the plastic bags and brought back to the laboratory for the characterisation.

2.1. Particle size distribution

Particle size distributions (PSD) of the saline soil samples were measured using the Malvern Mastersizer particle size analyser. The ethanol was used as dispersants and the suspension was ultrasonic treated for 20 min before the measurement. The results are shown in Fig. 1.

Table 1
Samples taken from the coastal area of Tianjin, China.

Sample No.	Distance from coastal line (m)
K1	0
K2	50
K3	100
K4	150
K5	200

The average size of the five samples ranged from 11.5 μm to 14.7 μm. The samples contained around 15% clay, 68% silt and 17% sand particles and could be classified as a silt loam. The clay content of the soil has a significant effect on the soil activity in stabilisation and workability in SCEB production. It was reported that strength of the samples stabilised with lime increased with the clay content [45]. Soils with clay contents less than 15–30% were reported suitable for SCEB production [7]. Ipinge [32] stated that block produced with above 15% clay content were difficult to remove from moulds whereas it produced with below 5% clay content difficult to handle in moving to curing area and concluded that the optimum clay content for handling purposes was between 5% and 10%. Therefore, the saline soil obtained in this study is suitable for SCEB production. However, introducing a portion of coarse particle materials, e.g., sand, into the mixture will improve the workability for achieving dense products with conventional vibration and/or compacting processes.

2.2. Soluble salts

Concentrations of various ions of the soluble salts of the samples were measured according to JTJ051-93 [46]. The total soluble salt was then taken as the sum of all ions measured and pH values of the samples were measured on solutions with 1:1 water/soil ratio. Concentrations of ions K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^2 and HCO^{3-} are given in Table 2, while the sum of soluble salts and the pH values of the solution are shown in Fig. 2.

As the average $(Cl^-)/2(SO_4^{2-})$ ratio of the samples was 0.28 (<0.3) and the (SO_4^{2-}) 0.7% (between 0.3 and 2.0), the samples can be catalogued as medium class sulphate saline soil according to GB50021-2001 [47]. Fig. 2 shows that the sample near the coastal line had the highest total soluble salts content, which ranged from 2.52% to 2.20% and decreased with an increase of the distance from the coastal line. Table 2 indicates that the ions Mg^{2+}, K^+, Na^+, Cl^- and SO_4^{2-} decreased significantly, however, Ca^{2+}, increased with the distance from the coastal line. There were no significant variations for the rest of the ions measured. The variation of the ions depends on the differences between the concentrations of the ions in the seawater and the primary salt-uncontaminated soil. When the concentration of an ion in the seawater is higher than that in the primary soil, the decreased ion concentration can be seen with an increase of the distance from the coastal line and vice versa.

The pH values of the samples ranged from 8.6 to 8.9, which indicate the soil is alkaline. The pH values tended to increase with the

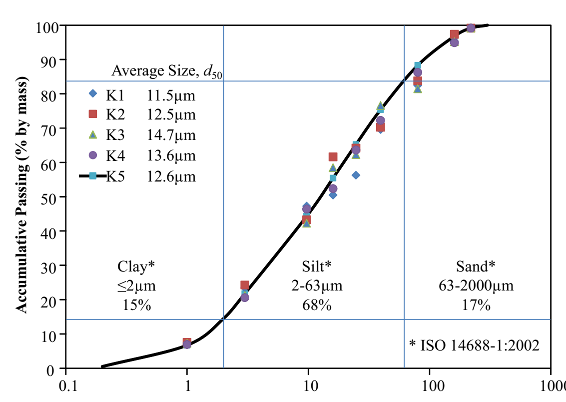

Fig. 1. Particle size distributions of the saline soil samples.