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Effect of wetting and air curing durations on strength of stabilized sands

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Abstract. Low cost houses in most developing countries are constructed from sandcrete blocks manufactured from sand-cement mortar. In South Africa, failure of many of these blocks has been experienced leading to collapse of the structures. Lack of sufficient compressive strength in the manufactured blocks was attributed as the main cause of the failures. The unconfined compressive strength (UCS) of sandcrete blocks can however be improved by curing the blocks under different conditions. Therefore the objective of this study was to evaluate the effect of different wetting and air drying durations would have on the strength and the stiffness of the cubes produced. Weakly cemented sand cubes, with different cement contents and cement-fly ash binder ratios compacted at the optimum moisture content, were prepared. The 28 days UCS was determined, modulus of elasticity and moisture contents of sample specimen was also determined. The results showed that curing cubes under water for 7 days and then air curing for 21 days yield maximum UCS and modulus of elasticity for sands cemented by plain Portland cement, and that 3 days under water curing produced maximum results for sands stabilized by cement-fly ash binder. It was however found that under water for 28 days results in minimum strength. Therefore the longer the cubes are cured under water minimum strengths were achieved.

Keywords. Sandcrete, fly ash, cement, unconfined compressive strength, stiffness

Introduction

Sandcrete blocks are widely used for the construction of low cost housing in many developing countries and are manufactured by mixing sand, cement and water in some predetermined proportion. The South African government with the aim to improve the living conditions of many of its people, contracts to build millions of low cost housing subsidised by the government under the Reconstruction and Development Programme (RDP) were issued to various contractors. As these are low cost houses, sandcrete blocks became the building bricks of choice by virtue of their low retail price. Failure of these blocks has been witnessed in varied applications with some even failing as they were being stacked post production, some while in transit, and many during construction. About three million low-cost houses have been built since 1994 using sandcrete blocks and the blocks were cured by sprinkling water once a day for seven days [3]. This method of curing has failed to consistently produce desired compressive strength for the blocks.

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The common use of this material as the main building block for these housing units remains the current reality and will arguably remain, into the immediate foreseeable future. Therefore, this large scale use gives rise to the need to study and understand the various factors affecting the development of compressive strength of these blocks and stiffness, and in particular the influence that different wetting and air curing durations and the mixing of fly ash in the cement have on their compressive strength development and stiffness. It has been proven that by 28 days under appropriate curing conditions concrete will gain above 95% of its strength, this study seeks to evaluate whether sandcrete cubes under the similar curing conditions would yield maximum strength or would require different curing conditions be used. The sandcrete failure has largely been attributed, in other studies, to the inadequate quality and quantities of the materials used in the manufacturing process, i.e sand aggregate, Portland cement and water. However the use of inappropriate methods for curing, further contributes to low strength blocks by failure to provide conducive conditions for adequate strength development. Several studies have been conducted and methods developed to analyse the effect of curing on the strength of cement mixes. Park [5] analysed the effect of wetting duration on unconfined compressive strength of cemented sands, and moisture conditions and temperatures for curing cemented sands. He found that when sprinkling curing is used on cemented sand, wetting for one day on the last day of twenty eight days decreased the strength while wetting for one day in the middle of 28 days curing, resulted in an increased strength. He also found wetting and drying over three cycles to be the most optimum period to increase strength, beyond which the strength decreased. This paper is subdivided into six parts, namely: introduction; materials and methods; results and discussions; conclusions and recommendations.

1. Materials and methods

Sandcrete blocks can be described as solid material made up of cement, sand and water which can be shaped into different sizes. A sandcrete block can be hollow or solid and can be utilized as load-bearing or non-load-bearing units [4]. These blocks are usually made up of cement to sand ratio of 1:6 and are supposed to have a minimum compressive strength of 2.5 – 3.45MPa as specified by the Nigerian Industrial Standard [2] and 3.2MPa according to the South African National Standards (SANS) 2001-CM1:2007, is required for masonry units used for wall building. Similar to normal concrete, sandcrete blocks are weak in tension and strong in compression.

A textural classification of sands, according to the Unified Soil Classification System (USCS), is soils with particle size smaller than 4.75mm but greater 0.075mm. Sands are primarily sourced from river and stream banks as they are predominantly transported through these mediums. Sands can also be produced through the process where rocks weather over many years caused by the prevailing climatic conditions into sand sized particles. Portland Cement is a fine mineral powder which chemically reacts when mixed with water to form a paste that sets and hardens; forming a rigid mass that binds aggregates together and AfriSam 52.5R cement was used. Fly ash is a product of pulverised coal combustion; fly ash rises with flue gases through the exhaust chamber and removed by electrostatic precipitators. The class F fly ash was used in this study. A series of laboratory testing was performed on the soil using the ASTM procedures. The soil classification tests, compaction tests on both plain and cemented sand were conducted. The compaction test for each cement content mix was performed to determine the optimum moisture content at which each mix shall be prepared to produce the sandcrete block of maximum dry density. Stabilized sand samples were prepared by mixing sand with different percentages of Portland cement and another set with a cement-fly ash binder as in Table 1 below.

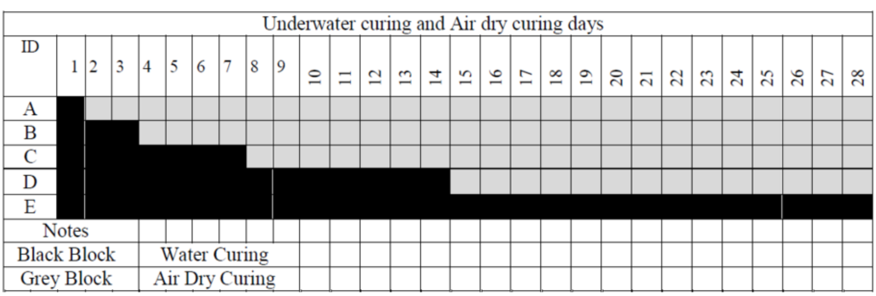
Table 1. Sandcrete cubes mix design

Binder content (%)	**W/C ratio**	**Sand (kg)**	**Water (%)**	**Water (l)**	**Number of cubes**
4	2.00	25.92	8	2.16	30
6	1.33	25.38	8	2.16	30
8	1.00	24.84	8	2.16	30
10	0.80	24.30	8	2.16	30
12	0.67	23.76	8	2.16	30

Note: 15 cubes of each 30 per group were stabilised using cement-fly ash binder.

Cubes were prepared by stabilizing sands with different ratios of cement or binder 4%, 6%, 8%, 10% and 12% percent by mass. For each stabilization ratio 30 cubes were cast 15 stabilized with cement the rest stabilized using cement-fly ash binder, where fly ash replaced 40% of the cement in the binder. In each 15 cubes, 5 groups of 3 cubes were formed to be cured under different conditions 1, 3, 7, 14 and 28 days underwater curing and the remaining days in a 28days period air dry curing. Therefore each group of cubes was separated by how many days they were soaked underwater. Therefore sample group A through to E were formed as shown in Table 2 with each consisting 30 cubes making a total of 150 cubes cast for this study. The mould of cubes were 150 x 150 x 150mm, stabilized sands were compacted into the mould by hand in 5 layers with 55 blows each layer at the optimum moisture content of 8%. After 28 days, the cubes were weighed and then tested for unconfined compressive strength in the Instron Compression Machine.

Table 2. Curing conditions and schedule



2. Results and discussions

The grading analysis of the soil depicts a poorly graded soil in Figure 1 where over 95% of the sample grain sizes are between #10 (2.0mm) and #200 (.075mm) sieve. The coefficient of uniformity of less than 4 as it is shown corroborates the soils' uniformity [1]. The sand is non-plastic with low shrinkage limit making the soil suitable for sandcrete block production see Table 3.

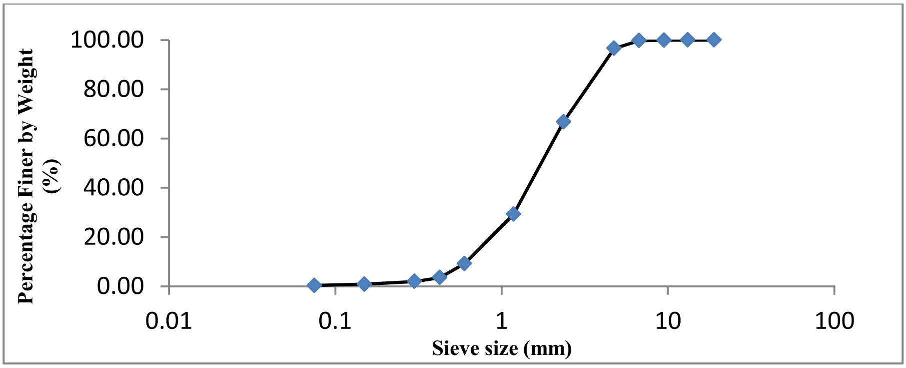


Figure 1. Particle size distribution

Table 3. Sand properties

Cu	Cc	D_{50} (mm)	D_{10} (mm)	LL (%)	PI (%)	SL (mm)	Gs	OMC (%)	MDD (g/cm^3)
3.55	1.24	1.7	0.6	18.9	0.45	0.63	2.63	7	1620

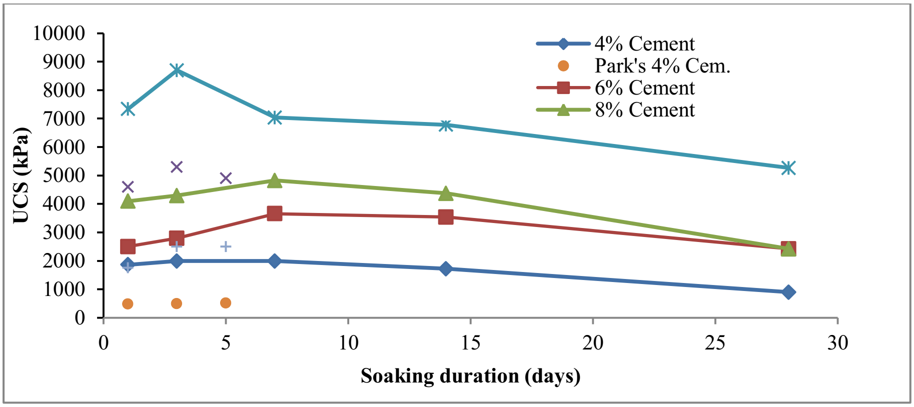


Figure 2. UCS and soaking durations for cement content

There is a gradual increase in strength as the number of days underwater curing increase reaching a maximum value on day 7 Figure 2. A more significant jump in strength is witnessed as the cement ratio increases to 12%, the strength of the lower cement ratio remained slightly steady until about day 14 was reached underwater and a gradual decrease in strength is shown beyond. The cubes soaked in water for the whole

28 days show the least strength, even at higher cement ratio. Because there exists an optimum water moisture content for a given cement ratio that will mobilize complete hydration necessary to facilitate cementation of sand grains under conducive curing conditions, however a further excess ingress of water may wash away the cementing material especially in higher cement ratio mixes [5]. Equation (1) describes the approximate statistical relationship developed from these results of the binder content (BC) and soaking days (SD) to the UCS. The coefficient of determination is 0.856 and the closeness of the UCS values to the predicted in Figure 3 further depicts the quality of the fit. According to the SANS 2001- CM1:2007, a minimum compressive strength of 3200kPa is required for masonry units used for wall building. As a result model (1) is valid for values of BC no less than 6%, and SD from 0 – 28 days for the minimum strength to be achieved. Though peak strength is reached at day 7 for plain cement, addition of Class F Fly ash (replacing 40% plain cement) using equation (1), samples reach similar strength values in just 3 days for 8-12% BC. Class F fly ash is a pozzolan material that reacts with the calcium hydroxide produced during the hydration of Portland cement to form additional cementitious compounds thereby assisting the hydrated Calcium Silicates to bind sand particles. Park's results [5] are incorporated in some of these figures to make some comparison, as seen in Figures 2 the 3 and 5 day wetting strength of Park's study is less than the current work's UCS value even at 12% cement ratio. It is worth noting however that the curing methodology and conditions, along with the cube sizes were different between the 2 studies.

$$\mathbf{UCS} = -46.301\,\mathbf{SD} + 884.583\,\mathbf{BC} - 2163.677 \qquad (R^2 = 0.856) \qquad (1)$$

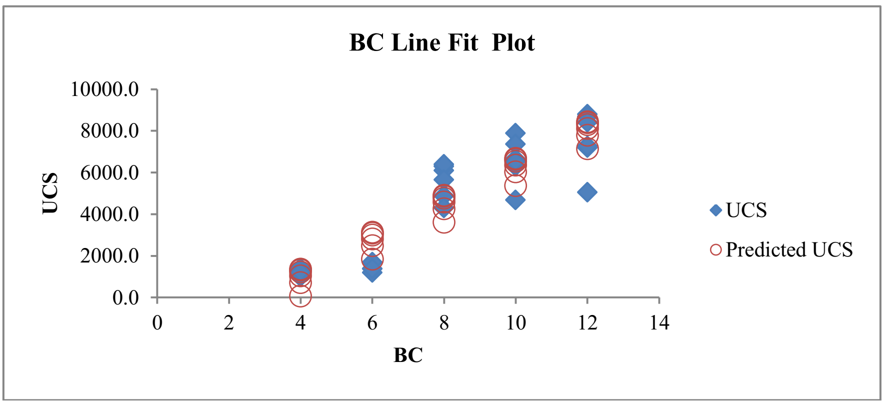


Figure 3. BC best fit plot

Modulus of elasticity (E) is a measure of stiffness of the stabilized sand obtained as the ratio of uniaxial stress over the uniaxial strain from the unconfined compressive strength tests. The result E versus Soaking duration showed a similar trend to the UCS in that for plain cement it peaked in 7 days at 290 MPa and for BC in 3 days at 321MPa.

3. Conclusions

The large scale use of sandcrete blocks construction in low cost housing in South Africa, necessitates a study to understand how sands can be stabilized to effect sufficient strength gain and efficiently. Sandcrete blocks gain most of their strength by soaking for 7 days when stabilized by plain cement. The replacement of 40% of the cement with Class F shortens the time required to gain strengths to 3 days for BC of 8-12%, while slightly improving the strength. The reuse of waste fly ash in stabilization is recommended to be practiced along with cement stabilization. This would enhance utilizing of local resources, improved energy management, reduced land disposal and environmental sustainability. Soaking the cubes with plain cement underwater for consecutive days produces higher strength than when it removed from the water in cycles. However, that increases the amount of water beyond that which is required for hydration process, resulting in weakly cemented sandcrete blocks. From the study, we can conclude that the quality of sandcrete blocks used for constructing low cost houses can be improved by curing them under water for 7 days, and the strength development can further be accelerated by replacing 40% of the cement with Class F Fly ash. Equation (1) with a coefficient of determination of 0.856 is proposed as an approximate expression to predict the compressive strength by SD and BC, which is defined for BC greater 6% and SD of 0 – 28days, to achieve minimum strength required for masonry units intended for wall building.

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