Trends in
Applied Sciences Research

ISSN 1819-3579

Academic Journals Inc.

www.academicjournals.com

Trends in Applied Sciences Research 9 (8): 406-424, 2014
ISSN 1819-3579 / DOI: 10.3923/tasr.2014.406.424

Investigation on the Use of Clayey Soil Mixed with Cow Dung to Produce Sustainable Bricks

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ABSTRACT
This study was conducted to investigate the significance of clayey soil bricks mixed with cow dung to construct sustainable and environmentally friendly buildings. The clayey soil was collected at about 5 km South of Okahandja and the cow dung was obtained from Rietfontein in the Omaheke region of Namibia. Analysis of all the test samples suggested that the California Bearing Ration (CBR) decreases as the amount of cow dung is increased across the entire sample. The cow dung was added as a reinforcing agent in different proportions. The compression test outcome suggests that the strengths of the bricks decrease with increasing cow dung content.

Key words: Clayey soil, cow dung, sustainable bricks, CBR, compressive strength

INTRODUCTION
With the increasing demand for low cost housing and high cost of building material, there is a need to explore sustainable approaches to the needs of the building industry. Bricks as the core material towards construction can be produced by clay which is processed either through sun-dried or burned. The latter however is an expensive and technically exhausting whereas sun-dried bricks can be produced by the layman. In order to ensure the durability and optimal strength output with sun-dried clay bricks, fibrous materials is believed to enhance such characteristics. This study intends to explore, how cow dung can be used to enhance the quality of clay bricks that can be used for low cost building construction in various communities around Namibia.

A solution to deal with expensive building materials towards construction can be done through the use of alternative materials, such as the use of naturally occurring clay containing soil which is then stabilized to produce bricks. Clayey soil bricks have been used since 4300 BC and are still widely used today (Krakowiak *et al*., 2011). Next to concrete and steel, masonry is the most used construction material on Earth. Clay has the property of forming a coherent sticky mass when mixed with water, being readily mouldable when wet but if dried retains its shape (Olokode *et al*., 2012).

The brick making technology is driven by using the soil on-site or near to the site and then a certain amount of fibre is mixed into the soil, depending on the characteristics of the soil and then stabilized by compaction, so as to improve the engineering properties of the produced bricks (Makunza, 2006).

This study is driven by the objective of making extensive use of raw earth, containing a natural component of clayey soil, as the main building material, aided by a fibrous material which in this case is cow dung. This is to develop technologies that are energy saving, eco-friendly and sustainable (Olokode *et al.*, 2012).

The scope of this study presents the fundamental investigation and procedures for the manufacture of the clay brick of which the constituents are clay, cow dung, sand, silt and water. The principal processes and procedures for forming the bricks are researched, tested, analysed and discussed and appropriate conclusions and recommendations drawn from it.

The specific objectives of this study are as follows:

- To determine the strength characteristics of the sample ratios by conducting a California Bearing Ratio (CBR) and a compression test
- To use the compaction test in order to determine the maximum dry unit weight and optimum moisture content of the respective samples
- To use sieve analyses to classify the soil and cow dung, to know which characteristics are being dealt with
- To use the different outcomes of the tests conducted to produce the bricks which themselves are cured for 14 days in direct sunlight, 30 and 90 days under controlled conditions, respectively
- To analyse the outcome of the tests conducted and use that to draw conclusions

SOIL STABILIZATION

Stabilizing soil aims to stabilize silt and clay against water to give it lasting properties when moisture is added. Three procedures are done for soil stabilization. These are shown in Table 1.

The improvement of soil for building material is done by adding stabilizers. Soils which have been treated through stabilization, consolidation which are well-graded, sufficiently moisturized, mixed and cured will produce bricks that are strong, stable, waterproof and long-lasting. The stabilizers in soil have the following effects: (1) The soil particles are bound together, resulting in a stronger product, (2) Waterproofing causes a reduction in the amount of voids and water absorbed and (3) The shrinkage and swelling properties are reduced and the tensile strength is increased (Makunza, 2006).

Stabilizers: Sandy soils require cement stabilization but also for the general achievement of quick higher strength. Clay containing soil requires lime, although this technique takes longer to harden and to give strong blocks. Either cement or lime stabilisation results in an increase in strength and the ability of the stabilised earth to be exposed or submerged in water. Compression which results in the densification of soils such as in rammed earth and Compressed Stabilized Earth Bricks (CSEB) or by the addition of water, such as for shaped, cob, adobe and wattle and daub gives the bricks a greater amount of cohesion and resistance, although they should not be exposed to water for long.

The thermal behaviour of earthen walls is referred to as hydrothermal behaviour which means that if the clay is only stabilised and not burnt, it retains the ability to absorb and release moisture through evaporation and condensation. This happens, when there is moisture and temperature difference between the outside and inside. This behaviour is called “latent heat” and is a daily and seasonal occurrence. This occurs as follows:

Table 1: Methods of stabilization

Principle	Actions
Mechanical	
A compaction in soil	Results in an increase in density and mechanical strength
	Results in an increase in water resistance
	The effect is a decrease in permeability and porosity
Physical	
Adding or removing aggregates corrects the texture of the soil	Coarse particles are removed by sieving
	Improvement in texture by mixing different soils together
	Gravel or sand is added for reinforcement
	Clay is added as a binder
Chemical	
The soil is mixed with processed products (which active materials) like chemicals	They aid in binding the soil together

- If there is a higher external temperature, then the moisture in the walls will evaporate, hence cooling the wall and the inside of the building
- If there is a lower external temperature, then the walls will condense moisture, releasing heat into the wall and consequently heating the inside of the building

Clay: Namibia has seven soil clay mineral regions, of which many individual clay mineral assemblages occur in fluvial, pan, cave and other environments. Clay minerals are the most common components of all sediments and soils. Figure 1 shows clay mineral provinces in Namibia.

Seven clay mineral regions in Namibia consist of clay mineral compositions containing quartz, feldspars, Fe-oxides (goethite), calcite, dolomite and a small amount of other non-clay species. In other words and as indicated in Fig. 1: Regions, (1) Contains kaolinite and smectite, (2) Has a composition of smectite (55%), illite (20%), kaolinite (15%) and illite/smectite/mixed-layer clay minerals (10%), (3) Is composed of illite (10-60%), smectite (40-70%), palygorskite (15-30%), chlorite (10%) and mixed-layer clay minerals (5%), (4) Is made up of illite (ca. 40%), smectite (ca. 40%) and kaolinite (ca. 20%), (5) Comprises of Illite (40-70%), Chlorite (ca. 25%), Smectite (up to 25%), kaolinite (up to 5%) and Palygorskite (Up to 10%), (6) Has a make up of illite (20-50%), smectite (15-30%), kaolinite (10-15%), a mixed-layer (up to 15%) and Palygorskite and sepiolite (up to 30%) and (7) is composed of illite (30-35%) and smectite (30-60%) dominate, Kaolinite and chlorite (up to 10%), a mixed-layer clay minerals (chlorite-smectite-forms) (a few percent), Palygorskite (35%) (Heine and Volkel, 2010).

Dung and straw offer similar advantages, where dung is added to additionally repel insects. Traditionally lime-based cement is used for the plaster to protect against rain damage.

Thermal properties: The wall of adobe bricks can serve as a heat reservoir because of its thermal properties inherent in the massive walls typical in adobe construction. Areas that have hot days and cool nights allow the high thermal mass of adobe to level out the heat transfer through the wall to the living space. The walls require a large and long input of heat from the sun (radiation) and from the surrounding air (convection) before they warm through to the inside of the building and begin to transfer heat to the living space. When the temperature drops after sunset, the warm wall, then continues to transfer heat to the interior for several hours due to the time lag effect. Therefore, an adobe wall of the appropriate thickness is very effective at controlling interior temperature through the daily fluctuations which contributes to its longevity as a building material. Rammed

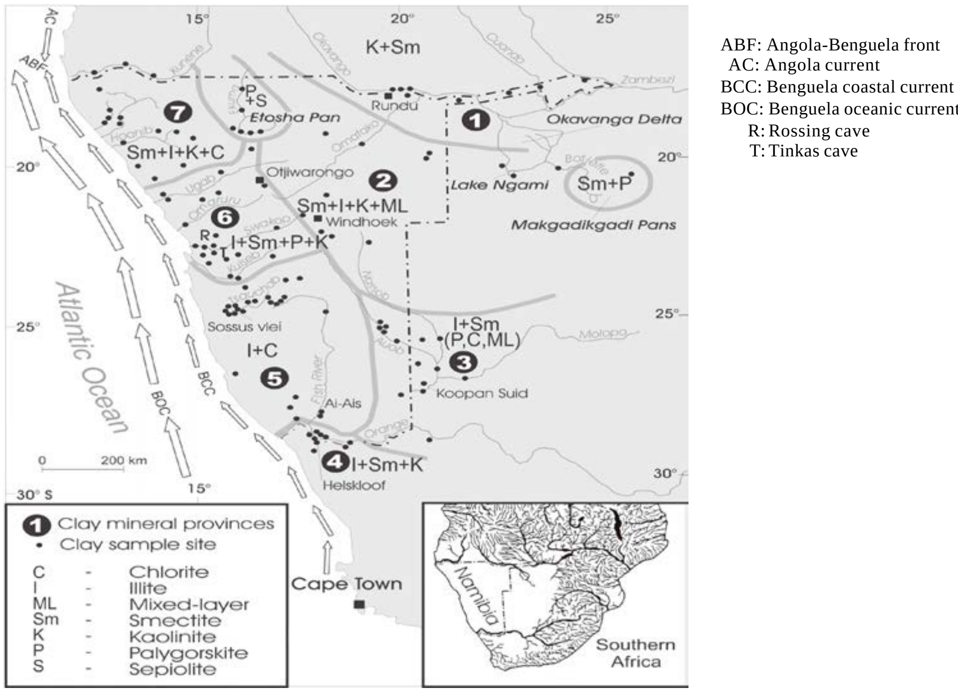

Fig. 1: Clay mineral provinces of Namibia. (Southern Africa perennial rivers), (Heine and Volkel, 2010)

earth can contribute to the overall energy-efficiency of buildings. The density, thickness and thermal conductivity of rammed earth make it a particularly suitable material for passive solar heating. Warmth takes almost 12 h to work its way through a wall 35 cm thick.

METHODOLOGY

In order to achieve the objectives of the experimental study, various sources of information were combined and adopted the following approaches, (1) To obtain information pertaining to the study at hand and then compile a concise guide of how to use the readily available materials and use that produce sustainable bricks and (2) Admixtures and stabilization techniques were also investigated, to see its effects when combined with the different constituents to obtain the best formula (optimum ratio).

Field visits and sample collection: In order to strengthen the argument, a sample area was selected from the total possible for the purpose of comparing theoretical and practical information.

Clayey soil samples: The study required traveling to the area falling within the town boundaries of Okahandja, since this area is known to have a good source of clay containing soils. A literature review conducted revealed that the Okahandja area would provide good samples which would give proper test results. The area is indicated in Fig. 2.

The samples were collected approximately 5 km before entering the town of Okahandja. Random soil samples were taken but within the immediate vicinity of each other to limit the variety of clay composition as well as to maintain consistency.

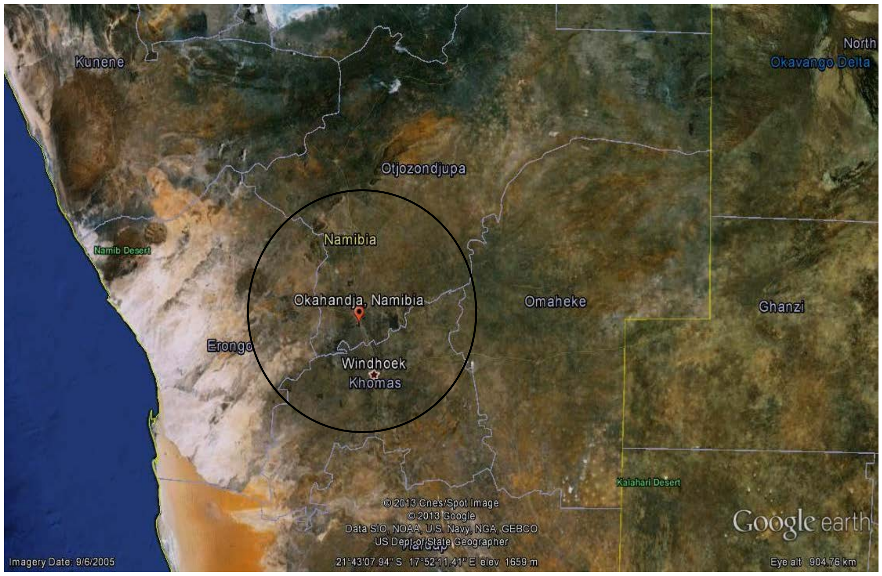

Fig. 2: Okahandja town area in the Otjozondjupa region from where the soil samples were collected (Google Earth in 2012)

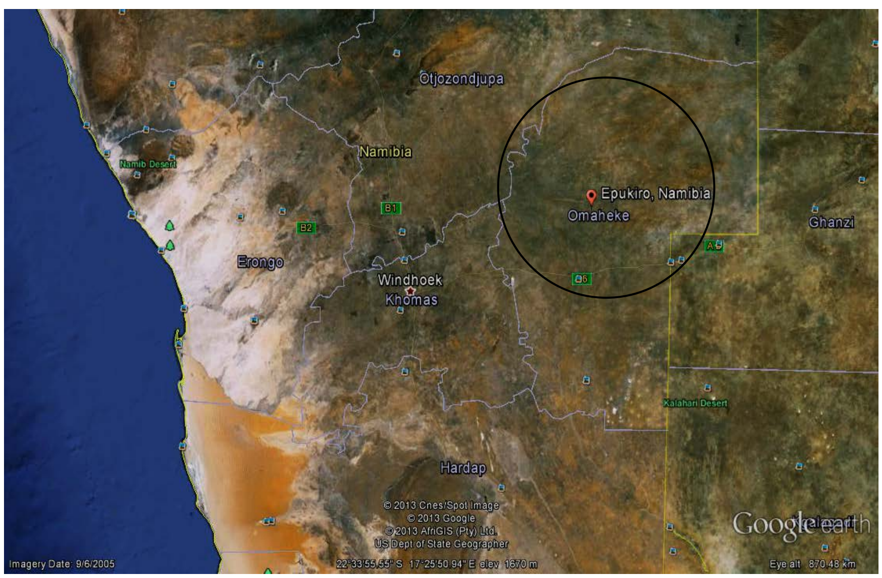

Fig. 3: Epukiro, the rural communal area in the Omaheke region from where the cow dung was collected (Google Earth in 2012)

Cow dung collection: The cow dung was retrieved from eastern Namibia in the Omaheke region, namely the Rietfontein rural communal farm area. The cow dung was from the Brahman herd of cattle which is frequent in this area. The area is indicated by Fig. 3.

The cow dung was collected in two forms, namely fresh cow dung which had just been dropped from the animal and dry cow dung which had been dropped but which was not older than 2 weeks (14 days). Both of the sample groups were described as 'fresh'. Cows are kept for two weeks in camps and then rotated thereafter. This controlled process ensured that the correct cow dung was collected. The wet cow dung was collected by the cattle herder within minutes after dropping, wrapped in several bags which was done to ensure that the moisture content of the samples were kept as close to the original as possible by keeping the temperature low and the bacterial activity to a minimum, hence, any losses can be considered negligible. The collected moist samples were used within 5 days in order to maintain consistency.

The moist cow dung was soft to the touch (the researcher wore gloves to protect against bacterial and pathogenic infection) and was a normal faecal colour, namely dark brown with a bit of dark green.

The other type of samples was that of the dry patches collected from the ground surface which were dropped and was lying on the surface for a period not exceeding 14 days. The dung patches were fairly dry and no strong odour was detected from it. The worms and beetles were also not noticed, although the undigested fibres were there, including additional vegetation becoming attached to the dung patches since, it fell on the ground. The urine may or may not have become part of the dung since the animals were trampling all over it.

Sieve analysis: The sieve analysis was conducted for both mixing ingredients, namely the clay containing soil and the dry cow dung. The particle size classification for this project was done using the classification developed by the American Association of State Highway and Transportation Officials (AASHTO). The sieve sizes used were in accordance with AASHTO sizes namely, 2.00, 1.18, 0.600, 0.425, 0.300, 0.150 and 0.075 mm and the bottom collection pan.

The test was conducted as per the normal sieve analysis process with a mechanical sieve shaker. The observation was however, that the clay particles had to be crushed with a pestle to even smaller particles, since smaller lumps were still present. Submerging the sample in water revealed that the soil had very small fines and that lets to the decision to conduct a wet sieve analysis for the finer particles. The dry sieve analysis was conducted as far as possible and then the soil washed through the sieves with water in order to disintegrate the finer particles to get a more accurate size distribution.

The wet sieve analysis was conducted three times in order to get a fair idea of the soil classification (Fig. 4).

Liquid limit test: Liquid Limit (LL) is the moisture content, expressed as a percentage by weight of the oven dry soil and is located at the boundary between the plastic and liquid states. For this study, the standard three point method was used. Sandy soils have no liquid limit because granular soils, do not exhibit cohesive properties and instead of flowing behaviour, either crumbles or collapses when tapped.

Plastic limit: Plastic Limit (PL) is the moisture content located at the boundary between the plastic and semi-solid state and is obtained by rolling a piece of soil between the fingers until a thread of approximately 3 mm in diameter is achieved. Here as above, the moisture content is expressed as a percentage of the oven dry material.

Fig. 4: Sieves on the mechanical sieve shaker

Plasticity Index (PI): This is the difference between the liquid and plastic limits, meaning it is the range of moisture content in which the soil is in the plastic state

$$\text{Plasticity index} = \text{Liquid limit} - \text{Plastic limit} \quad (1)$$

Compaction test (Modified proctor test): The dry unit weight is plotted against the corresponding moisture contents to get the maximum dry unit weight and the optimum moisture of the soil. The theoretical maximum dry unit weight at given moisture content is when there is no air in the void spaces and the degree of saturation is 100%. Other factors affect soil compaction apart from the moisture content such as described as:

- **Effect of soil type:** The type of soil deduced from the grain-size distribution, soil grain shape, specific gravity of soil solids and amount and type of clay minerals present significantly influences the maximum dry unit weight and optimum moisture content
- **Effect of compaction effort:** The proctor test uses the compaction energy per unit volume given as:

$$E = \frac{(\text{No. of blows/layer}) \times (\text{No. of layers}) \times (\text{Weight of hammer}) \times (\text{Hammer height})}{\text{Volume of mould}}$$

A change in the compaction effort per unit volume of soil changes the compaction curve; that is, both the optimum moisture content and the maximum dry unit weight (Das, 2005). The proctor compaction effort was used to produce the bricks.

Preparation and compaction of the sample: The samples were prepared by mixing different ratios of clayey soil and cow dung in order to find a ratio of suitable combination. The ratios of

Fig. 5: Automatic compaction machine

clayey soil, soil to cow dung used were; 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 90:10 and 100:0%. Compaction was done in a CBR mould using a 2.5 kg hammer falling 305 mm; giving 62 blows per layer in 3 layers.

The samples were compacted in the automated compaction machine (Fig. 5) to ensure that the compaction energies used were uniform and consistent for the different samples.

California Bearing Ratio (CBR) test: The California Bearing Ratio the material was done according to (TMH1-A8, 1986) standard. This is the load in Newton's, expressed as a percentage of California standard values, required for a circular piston of 1935 mm^2 to penetrate the surface of a compacted material at a rate of 1.27 mm min^{-1}. The California standard values are shown in Table 3. The testing setup is shown in Fig. 6.

Brick production process, curing and testing: The bricks were made in the laboratory using brick making machine shown in Fig. 7. The individual brick moulded in this machine had dimensions of 230×110×85 mm. This ensured that all the bricks produced in this machine were of the same initial size before treatment and exposure. The samples for each of the mix ratios were placed in the mould and compacted using Proctor equivalent compaction effort. Figure 7 shows the brick making mould used to produce the brick test samples. The bricks made were then cured using two methods, air drying and sun drying. The bricks were tested for shrinkage and compressive strength after curing. Figure 8 shows the compression testing equipment used to measure the compressive strength of the test samples.

RESULTS

Figures 9 shows a brick test sample after production and Fig. 10 shows different failure modes. A force-penetration curve was drawn for each of the main sample mixtures, as well as the sub-mixes separated by the moisture content on a natural scale i.e., the load readings were plotted

Fig. 6: California bearing ratio testing equipment

Fig. 7: Brick making mould used to produce the brick testing samples

Table 2: Forces for a 100% CBR at specified penetrations (TMH1-A8, 1986)

Penetration (mm)	California standard (kN)
2.54	13.344
5.08	20.016
7.62	25.354

against the depth of penetration. The loads were read off at 2.54, 5.08 and 7.62 mm points of penetration where the force readings were then expressed as a percentage of the California Standard loads shown in Table 2. The percentages thus obtained are the California Bearing

Fig. 8: Compression testing equipment used to measure the compressive strength of the test samples

Fig. 9: Brick test sample after production and during curing period

Fig. 10(a-c): Brick test samples showing the compressive strength failure modes

Ratios (CBR) at the particular depths of penetration. The values of CBR at 2.54 mm penetration were generally used to assess the quality of the materials. Below, however a combination of all three was used to gain an overall view of the behaviour of the soil and cow dung mixtures. Table 2 and 3 show the relationship of depth of penetration with the California Standard to determine CBR (TMH1-A8, 1986). Results of CBR are shown in Fig. 11 and 12, respectively.

Figure 13 to 15 show the California Bearing Ratio (CBR) graphs (Load vs. Penetration) of sample 0 at 220 mL of water added and Table 4 and 5 show the CBR peak values at the penetration values 2.54, 5.08 and 7.62 mm.

Table 6 and Fig. 16 show the particle size distribution analysis for the clayey soil and Table 7 showing article size characterization of the clayey soil, while Table 8 and Fig. 17 show the

Table 3: Laboratory readings of the california bearing ratio (CBR) of the clayey soil control sample

Penetration (mm)	Dry (No. 1)	100 mL	220 mL	650 mL (No. 2)	Dry (No. 1)	370 mL	520 mL	650 mL (No. 2)
0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000
0.635	0.625	0.075	1.500	0.050	0.000	1.050	0.025	0.050
1.270	0.950	0.500	3.100	0.050	0.050	1.450	0.050	0.075
1.905	1.775	1.150	4.425	0.050	0.225	2.175	0.075	0.100
2.540	2.325	1.975	5.275	0.075	0.525	2.950	0.125	0.150
3.175	2.650	2.675	5.800	0.100	0.925	3.800	0.150	0.150
3.810	2.825	3.250	6.225	0.125	1.425	4.650	0.200	0.200
4.445	2.950	3.700	6.625	0.125	1.925	5.450	0.225	0.200
5.080	3.025	4.025	6.800	0.150	2.375	6.150	0.300	0.225
5.715	3.050	4.300	7.100	0.150	2.750	6.725	0.350	0.275
6.350	3.050	4.450	7.350	0.175	3.000	7.225	0.400	0.300
6.985	3.050	4.600	7.550	0.175	3.200	7.625	0.500	0.350
7.620	3.050	4.650	7.775	0.175	3.375	7.925	0.600	0.400
8.255	3.050	4.650	8.000	0.200	3.475	8.150	0.650	0.450
8.890	3.050	4.650	8.200	0.200	3.625	8.400	0.750	0.450
9.525	3.050	4.650	8.400	0.225	3.700	8.575	0.850	0.500

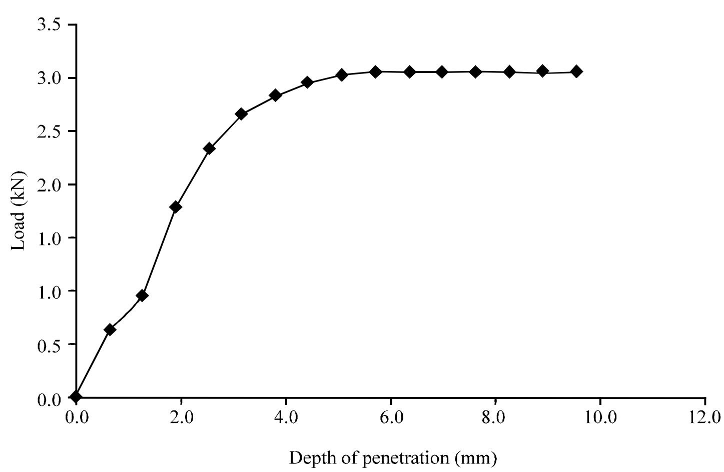

Fig. 11: California Bearing Ratio (CBR) graph (Load vs. Penetration) of sample 0 at 0 mL of added water (control test)

Table 4: Peak CBR values (TMH1-A8, 1986)

Penetration (mm)	CBR values
2.54	5.275
5.08	6.800
7.62	7.750

Table 5: Peak CBR values

Penetration (mm)	CBR values
2.54	0.525
5.08	2.375
7.62	3.375

Table 6: Wet sieve analysis of clayey soil (sample 1)

Sieve (mm)	Total sample weight retained on sieve (g)	Cumulative weight retained (g)	Percentage of soil retained on each sieve	Percentage passing
2.000	1.287	1.287	0.13	99.87
1.180	192.908	194.195	19.53	80.34
0.600	91.649	285.844	9.28	71.06
0.425	18.027	303.871	1.83	69.23
0.300	129.595	433.466	13.12	56.11
0.150	251.530	684.996	25.47	30.64
0.075	156.129	841.125	15.81	14.84
Pan	146.517	987.642	14.84	0.00
Total sample weight (g)	987.642			

Table 7: Particle size characterization of the clayey soil

Characteristics	Particle size
Effective size (D_{10})	0.060
Uniformity coefficient (C_u)	5.670
Coefficient of gradation (C_z)	1.260

Table 8: Dry sieve analysis of cow dung (sample 1)

Sieve (mm)	Total sample weight retained on sieve (g)	Cumulative weight retained (g)	Percentage of soil retained on each sieve	Percentage passing
2.000	1.080	1.08	0.11	99.89
1.180	61.010	62.09	6.14	93.75
0.600	171.710	233.79	17.28	76.47
0.425	80.030	313.82	8.05	68.42
0.300	172.260	486.09	17.34	51.08
0.150	271.050	757.14	27.28	23.81
0.075	164.800	921.94	16.58	7.22
Pan	71.780	993.72	7.22	0.00
Total sample weight (g)	993.717			

particle size distribution for the cow dung and its particle size characterization results are shown in Table 9.

Analysis of results: A particle size distribution curves were used to determine the following three parameters for the clayey soil and the cow dung:

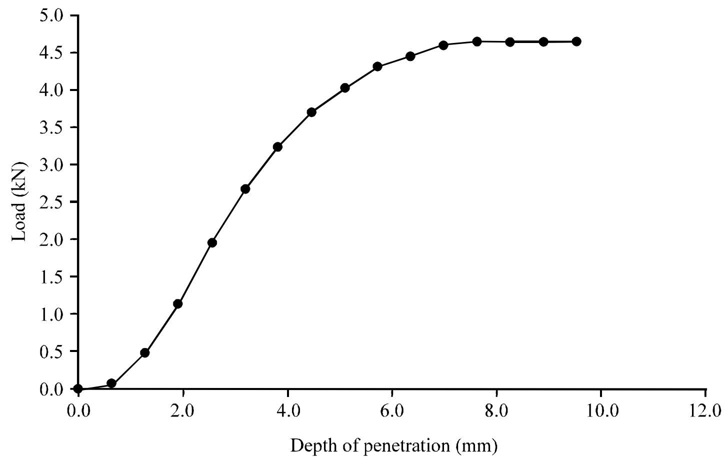

Fig. 12: California Bearing Ratio (CBR) graph (Load vs. Penetration) of sample 0 at 100 mL of added water

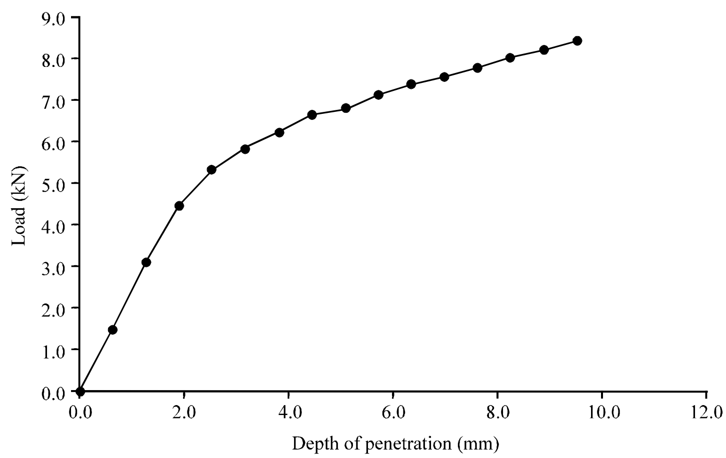

Fig. 13: California Bearing Ratio (CBR) graph (Load vs. Penetration) of sample 0 at 220 mL of added water

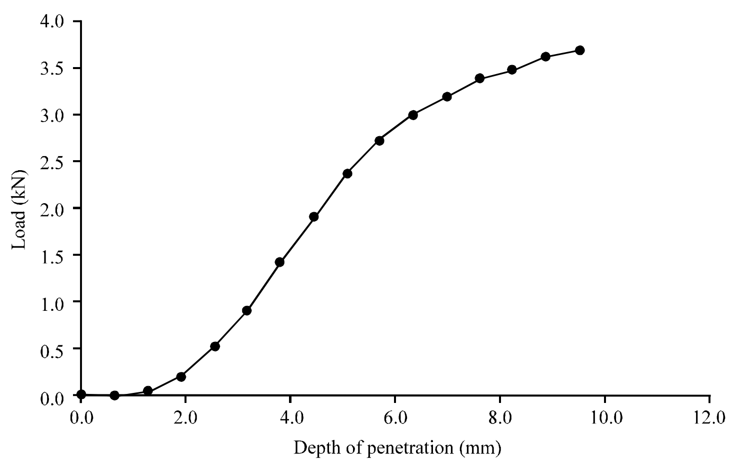

Fig. 14: California Bearing Ratio (CBR) graph (Load vs. Penetration) of sample 0 at 0 mL of added water (second trial run)

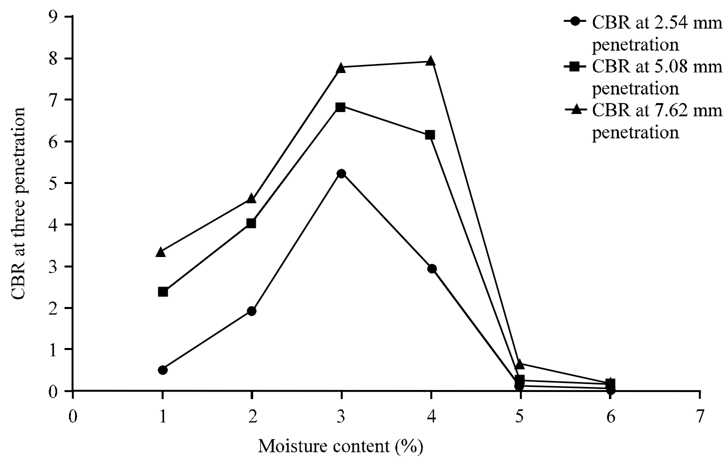

Fig. 15: A summary of the CBR values for all the samples

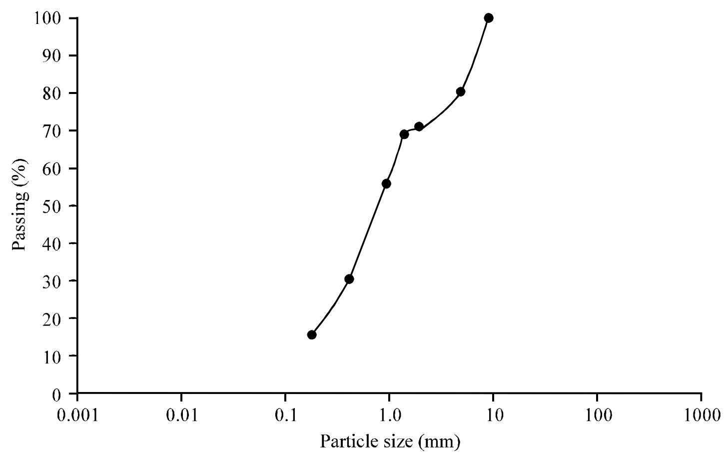

Fig. 16: Grain size distribution using wet sieve analysis of clayey soil sample

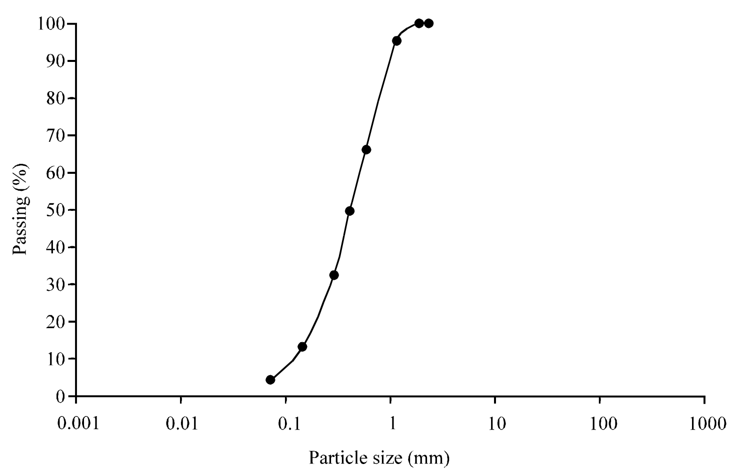

Fig. 17: Grain size distribution of the cow dung

Table 9: Particle size characterization of the cow dung

Characteristics	Particle size
Effective size (D_{10})	0.135
Uniformity coefficient (C_u)	3.889
Coefficient of gradation (C_z)	1.146

Table 10: Constituents of the clayey soil sample

		Sample		
Grain size (mm)	Soil type	1	2	3
Size limits greater than 4.75 mm	Gravel	0.00	0.00	0.00
Size limits between 4.75 and 0.075 mm	Sand	85.16	92.78	94.59
Size limits less than 0.075 mm	Silt and clay	14.84	7.22	5.41

Table 11: Sample data

Sample No.	D_{10}	D_{30}	D_{60}	C_u	C_z
1	0.060	0.160	0.34	5.670	1.2550
2	0.080	0.185	0.37	4.625	1.1560
3	0.088	0.165	0.34	3.864	0.9099

Table 12: Soil classification

Liquid limit	Plastic limit	Plasticity index
21	16	5
Results	Clayey silty sand	Fines are inorganic soil of low plasticity
Unified soil classification system	Coarse grained soil	
	Poorly graded inorganic clayey silty sand	

- **Effective size (D_{10}):** This is the diameter in the particle-size distribution curve relating to 10% finer
- **Uniformity coefficient (C_u):** This is defined as:

$$C_u = D_{60}/D_{10}$$

where, D_{60} is diameter corresponding to 60% finer

- **Coefficient of gradation (C_z):** This is defined as:

$$C_z = D^2_{30}/(D_{60} \times D_{10})$$

Table 8 and 9 show these values. Using AASHTO the clayey soil was separated into its constituents as shown in Table 10.

Using the particle size distribution in Fig. 17 and the analyses in Table 11 and 12 this soil was classified as a poorly graded clayey silty sand with group symbol SP-SM-SC (ASTM, 2000). The cow dung was classified as organic soil.

The specific gravity of the clayey soil sample was measured to be 2.57. The clay map of Namibia in Fig. 3 suggests that this soil most likely clay minerals would be Ilite, Kaolinite and Smectite.

Compaction test-modified proctor test: The compaction test results for the clayey soil are shown in Table 13 and Fig. 18. The graph shows that the optimum moisture content was 8% and the maximum dry unit weight was 20.4 kN m^{-3}.

Brick strength results: The results of the compressive strength of the bricks are shown in Fig. 19-21 These show the strength of the bricks after 14, 30 and 90 days of curing.

Table 13: Compaction energy comparison for brick making machine

Quantity	Modified proctor test	Brick mould
Volume of mould (m^3)	0.00234	0.0021
Number of blows	62.00000	50.0000
No. of layers	3.00000	3.0000
Weight of hammer (kN)	0.02500	0.0720
Height of hammer (m)	0.30000	0.1200
Compaction energy per unit volume of soil in modified test		
(Number of blows per layer×No. of layers×weight of hammer×height of drop of hammer)/volume of mould (kN-m m^{-3})	595.40000	595.4300

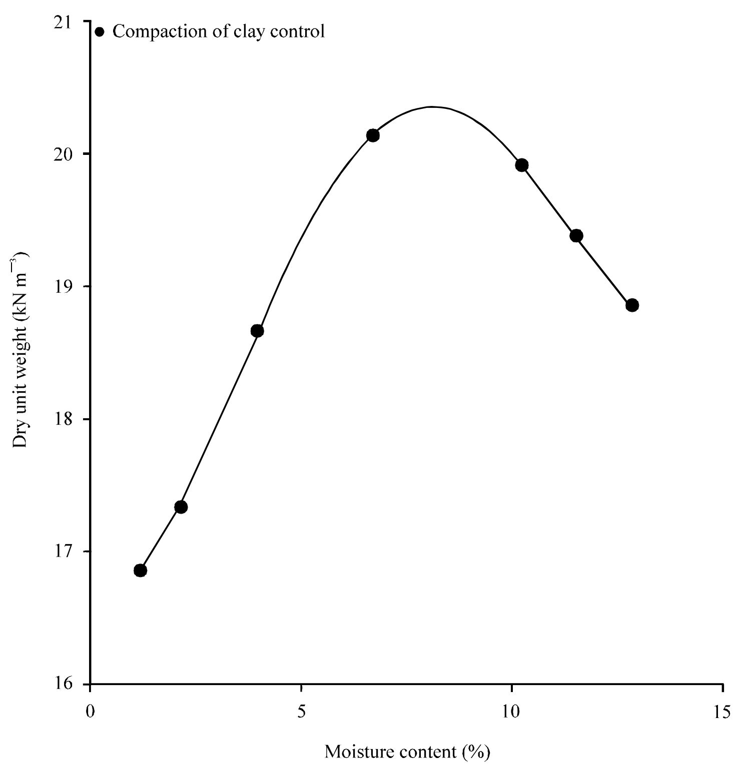

Fig. 18: Optimum moisture content and maximum dry density of sample 0-the clayey soil control sample

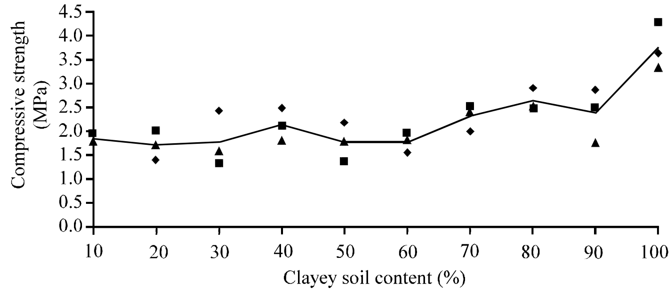

Fig. 19: Variation of the compressive strength against clayey soil proportion for the bricks at 14 days of curing (sun dried)

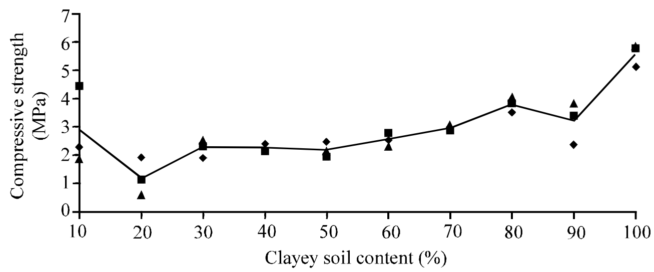

Fig. 20: Variation of the compressive strength against clayey soil proportion for the bricks at 30 days of curing (in the shade)

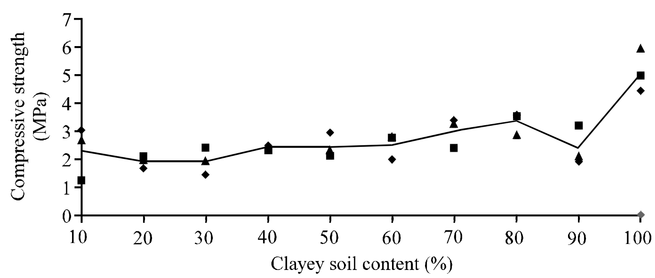

Fig. 21: Variation of the compressive strength against clayey soil proportion for the bricks at 90 days of curing (in the shaded)

DISCUSSION

Soil and cow dung classification: The results shown in Table 7-11 as well as Fig. 16 and 17 suggest that the clay containing soil and the cow dung has similar particle definitions, although the effect size diameter, D_{10} of the cow dung is slightly larger than the clay containing soil. The clayey the soil has close to 15% fine grained particles with the plasticity information indicating that the fine material is a mixture of clay and silt. This provides enough binding clay for useful production of the bricks. This soil was classified as SP-SM-SC, a poorly graded clayey silty sand. The cow dung may be classified as organic silty sand.

Samples after compaction test: The results due to compaction of suggests that an increase in cow dung reduces the maximum dry unit weight and increases the optimum moisture content. The clay containing soil is by weight approximately twice as heavy as the cow dung and by volume the cow dung is approximately twice as volumetric as the clay containing soil.

California Bearing Ratio (CBR) behaviour: The outcome of the results obtained suggests that the CBR is greatest, when the sample is in the region of optimum moisture content and maximum dry unit weight. A further analysis of all the test samples and the associated tables indicated that the CBR decreases as the amount of cow dung is increased across the entire range investigated. The cow dung was added as a reinforcing agent, however, too much of it has the effect of reducing the bearing capacity of the final brick product.

Compressive strength: The strength results displayed in Fig. 19-21 show that the compressive strength of the bricks increased with a reduction in the amount of cow dung in the brick material mixture. The graphs suggest that the sample with 20% cow dung content had a local maxima compressive strength and then continued to rise to the greatest values at 0% cow dung content. An alternative view is that there was a local minima at 10% cow dung. This trend around the 10 and 20% cow dung content may also be testing variability. This trend of increasing strength suggests that the strength increment expected from the added reinforcement coming from the cow dung was less than the reduction that accompanied the reduction in the clay binder coming from the clayey soil. This trend was true for all the curing periods used in this investigation.

Effect of the duration of curing: The curing process was just the driving off of the moisture using a natural drying process (both sun drying and air drying). The strength of clay increases as the moisture content is reduced. The apparent cohesion of granular material disappears when the soil is completely dry or fully saturated. This behaviour is displayed by the results in Fig. 19 to 21. The strengths for all the curing period were similar for low values of clayey soil content (10 to about 40%). Clayey soil contents greater than 40% had similar strength for the 30 and 90 days curing, while 14 days curing had strengths that were about 40% weaker than that of 30 and 90 days curing. After 30 days curing there was little further change in the moisture content and hence the strengths of the bricks.

CONCLUSION

The strength of the soil cow dung mixture decreases as the percentage of cow dung content increases. A local maxima in strength was observed at 20% cow dung content. This could conversely be read as a local minima at 10% cow dung content.

Curing of the soil cow dung mixture did not produce a great deal of difference in strength up to about 40% soil content. The strength difference became bigger for clay content greater than 40% and for curing between 14 and 30 days.

This is part of an investigation into the engineering behaviour traditional Namibia construction methods and materials. It would therefore be necessary to extend this study by carrying out durability testing of the bricks and wall systems made using them. Thermal testing to see, how the heat dissipates through the bricks and hence the walls would also be part of this extended investigation.

ACKNOWLEDGMENTS

This study is part of a broad program to investigate the use of various materials, (waste and indigenous) found in Namibia for use in the construction of houses. The Authors are grateful to the Namibia University of Science and Technology that sponsored the publication of this article and Derrek Basson for his Participation in material testing.

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