A Model for Testing Compressive and Flexural Strength of Sisal Fibre Reinforced Compressed Earth Blocks in the Absence of Laboratory Facilities

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Abstract

This study proposes a method of indirectly evaluating strength and therefore durability characteristics of compressed earth blocks in the absence of the normally expensive laboratory facilities. The method, with respect to compressed earth blocks reinforced with sisal fibres, is recommended for application particularly in rural areas of Africa. The developed method entails loading a compressed earth block sample with increasing amounts of weight till the sample raptures (total dead weight) under the load. The weight is then taken and a comparison is made with the standard value of compressive and flexural strength of the said sample. A conversion factor between this developed method and the conventional way of determining compressive and flexural strength has been computed. It has been established that the total dead weight is 47.25 times the flexural strength while the same is 66.4 times the compressive strength. The primary advantage of the proposed method is that it can easily be adapted at village level by people who have little scientific knowledge.

Keywords: compressive strength, conversion model, flexural strength, sisal fibers, total dead weight

1. Introduction

The subject of this study falls under what is now considered in many circles as Appropriate Technology. The term refers to application of techniques that best fit a particular people, community or society; this is, in part pegged to economic conditions, availability of raw materials, cultural orientation and geo-climatic environmental conditions. With respect to building materials [1], considers appropriate technology, as the application of techniques appropriate to the user, society and nature. Appropriate construction reflects therefore to the concept of "Ecological Building". Other schools of thought put appropriate technology at par with "Alternative Technology", a term used to describe some compromise situation between the very high technologies of the developed societies and the low technologies associated with the poor economies [2]. Principal characteristics of intermediate technologies are that they are cheap, small in scale and use relatively simple production methods from locally available raw materials. Appropriate or alternative technologies are therefore seen to be in harmony with nature, and have as a prime orientation, to provide sustainable solutions to issues related to human development.
The need to provide more housing for the worlds' poor societies cannot be overemphasised. Shelter is, after all, a basic requirement of human being. As concerns the developing nations, it is already recognised that the huge

housing requirement cannot be met with industrially produced building materials [3]. Indeed, 25% of the world's population does not have any fixed abode, while 50% of the urban population lives in slums [4]. In spite of the many effort such as "Global strategy for housing by the year 2000" declaration by the UN, the shelter issue remains a major problem, and hence the need to look at possible solutions including scientific research.

It is most likely that the majority of the people in the developing world will, out of necessity, continue to live in mud (earth) houses, consequently, ways of improving on this traditionally built mud houses are a subject of concern to many researchers. Compressed earth block (CEB) construction is one of the most widely used technologies in building with earth and has been adopted as the improvement to rammed mud houses. The key future of the technology is the compression of the soil in a mould with the help of a press at a compaction effort of 2-4 MN/m^2 [5]. Although Soil (earth) has been used as a building material for thousands of years, unprotected structures seldom withstand wet climates for long periods of time. Relatively new materials such as cement have meant that blocks can be made which will last for centuries, but they are too expensive for most people in developing countries. Traditionally built mud houses or ones constructed from compressed earth blocks made only of unfired earth have become a cheaper option. Properties of soil as a building material should therefore be further studied.

Several possible solutions have been forwarded by past researchers in bid to add strength and add durability to the earth raw material, even in less arid conditions, thus:

By using stabilizers that improve within the element characteristics of the soil, by appropriate architecture, i.e. earth building made with suitable design, by using bonding mortar to improve the structure or by applying plaster and renders on the building surface.

The idea to use renders, paints or plasters on the external surface can protect the CEB from external attack, but these are expensive processes and hence not suitable for a developing society, additionally, expansion rates between soil blocks and renders/plasters mortars are different resulting in to peeling. According to Montgomery [6] use of appropriate architecture is also hindered due to costs and skills required. Application of stabilizers as a remedy to the soil instability problem or for improvement of the durability of compressed earth blocks appear, from literature survey, to be fairly widespread and most successful way of improving strength to soil. Many types of stabilizing agents are known [3], [5], [7]; although not much research appears to be available, the most tried ones are: cement, lime, gypsum and bitumen (mineral products), animal products, artificial (manufactured) products and fibres (e.g. plant fibres). Earth blocks stabilized with 3 – 12 % mass of cement seem to be the most common [8]. As [2] correctly points out, the potential of soil as a building material has been considerably underestimated, the reason being, that the enormous variety of naturally occurring soils has made specification for any particular set of properties difficult and that many soils in untreated state lack strength and dimensional stability.

The use of natural fibres as a building material poses a special challenge to science and technology. Their use can, whilst alleviating the housing problem, assist [9] save energy, conserve scarce resources and protect the environment. Although research data is not quite abundant, some workers have documented the issue of using natural fibres as stabilising or reinforcing agent in earth construction. In discussion on kinds of stabilizers [7] recognises straw (wheat, rye, barley, etc) and plant fibres (sisal, hemp, elephant grass, coir and bagasse) as an important category of stabilizers but provides no much scientific findings. Namango and Diana [10] catalogue the use of sisal as a reinforcement of compressed earth blocks. The authors report a 9.14 N/mm^2 28-day strength for bocks reinforced with 0.75% sisal fibres by weight as compared to a 8.24 N/mm^2 28-day strength for bocks reinforced with 12% cement by weight.

The main purpose of this research study was to develop a strength and therefore durability testing method for compressed earth blocks that can be used in the absence of laboratory facilities. The method is hence applicable mainly in the rural areas. This was accomplished by determining a conversion function between standard laboratory tests and the proposed simple testing method i.e. total dead weight. The total dead weight for each block sample was correlated to compressive and flexural strength.

2. Background of the study

It has generally been established that, compressive strength and flexural strength are the common criteria for determining quality of compressed earth blocks. [11] Reports that quality control strength testing of compressed earth blocks has often followed procedures developed for fired clay and concrete block units [12]. However, the suitability of these procedures has largely not been checked by scientific study. The compressive strength of compressed earth blocks can be many times lower than similar fired bricks. Resistance is also significantly influenced by moisture content. Previous studies have reported on the compressive strength characteristics of compressed earth blocks [13], [14], [15], [16], [17], [18], [19], [20]. Strength is improved by compactive effort (density) and cement content (generally linear correlation), but reduced by increasing moisture content and clay content (cement stabilized blocks). National and international standards have also developed for compressed earth block test procedures [21], [10], [22], [23], [12]. However, unlike other masonry units, there is little general consensus on test procedure for compressed earth blocks.

According to Morel [11] a small number of indirect compressive strength tests have been developed, primarily in order to allow in situ quality control testing of materials in the absence of laboratory testing facilities. The most widely quoted indirect test methodology is the three-point bending test. Blocks are subject to single point loading under simply supported conditions through to failure. Forces required to induce failure in this manner are typically 80–150 times lower than that required to induce failure under uniform compression and as such are normally quite achievable under site conditions, without resort to sophisticated equipment. Flexural failure stress is calculated assuming pure bending (maximum moment divided by elastic section modulus), ignoring the other potentially significant effects such as shear and compressive membrane action (arching). Correlation between compressive and three-point bending strength has been established experimentally by a number of workers; results show considerable scatter but there is widely considered to be sufficient evidence to enable lower bound prediction of compressive strength based on flexural strength [24]. Design guidelines and standards have adopted this approach. Disadvantages of the test method include susceptibility to defects in the blocks (shrinkage cracks). Another, less widely accepted, indirect test method is the splitting test, akin to the Brazilian test used for concrete, in which the block is loaded in compression through two thin steel bars along opposing faces. This, argues Morel [24] induces indirect tensile stress, causing the block to split along the line of the load. The advantage of this methodology is the greatly reduced forces required to induce failure. Blocks from this test can also be used in the RILEM compression strength test, enabling direct correlation between the two measured results.

For determination of standard compressive and flexural strength in the present study, each specimen of compressed earth blocks reinforced with sisal fibres was loaded in a TONIVERSAL-TONITECHNIK hydraulic press at a rate of 1.5 $N/mm^2/s$. the cut blocks were placed centrally between the lower and upper sides to provide for uniform distribution of the compressive force. The flexural strength was conducted by uniaxial point loading on TONIVERSAL-TONITECHNIK hydraulic press at a rate of 0.05 kN/s. Results of the standard compressive and flexural strength are reported by [10].

3. Experimental Program

3.1 Soil Sample

Full blocks were fabricated using soil collected from the town of Bautzen in Germany. In order to obtain initial uniform moisture content, the soil was stored in the open at a room temperature of 22 °C and relative humidity of 65 – 70% for five months before being broken down and passed through a 2mm sieve. The soil's Atterberg limits were determined according to [25], the optimum moisture content according to [26], the organic component according to [27], while the particle size distribution was established by sedimentation using [28]; these results are illustrated in table I

TABLE I

ATTEMBERG LIMITS, SEDIMENTATION RESULTS, LOS ON IGNITION AND OPTIMUM MOISTURE CONTENT OF SOIL SAMPLE

S. No.	Item	Quantity, %
1	**Grading**	
	Gravel Fraction	0.0
	Coarse Sand Fraction (0.6 – 2 mm)	0.0
	Medium Sand Fraction (0.2 – 0.6 mm)	2.0
	Fine Sand Fraction (0.06 – 0.2 mm)	18.0
	Coarse Silt Fraction (0.02 – 0.06 mm)	32.0
	Medium Silt Fraction (0.006 – 0.02 mm)	22.0
	Fine Silt Fraction (0.002 – 0.006 mm)	6.0
	Clay Fraction (≤ 0.002 mm)	20.0
2	**Atterberg Tests**	
	Liquid Limit (LL)	28.9%
	Plastic Limit (PL)	18.3%
	Plasticity Index (PI)	10.6%
	Linear Shrinkage %	
3	**Optimum Moisture Content (OMC), %**	14.0%
4	**Los on Ignition (LOI), %**	2.138%

By application of Roentgen diffractometry method (Philipps-Diffractometer PW1050 equipment) it was possible to establish that the soil sample contains the following 3-layer clay minerals: Mica, swelling clay minerals (Montmorillonite DSTM) and Chlorite. The non-clay minerals present are Silica and Feldspar. Table II shows the proportion of each mineral in the soil sample, while table III depicts the chemical composition.

TABLE II

MINERAL COMPOSITION OF SAMPLE SOIL

S. No.	Bautzen Soil					
		Non-Clay Minerals		Clay Minerals		
1	Mineral Type	Silica	Feldspar	Chlorite	Montmorillonite DSTM	Mica DSTM
2	Mineral Content, %	51	16	8	8	16

TABLE III

CHEMICAL COMPOSITION OF SAMPLE SOIL

S.No.	Type and Quantity of Chemical Compound %								
1	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	Fe_2O_3
2	0.84	0.87	13.37	69.93	-0.17	3.69	0.72	1.11	9.64

3.2 Sisal and Cement Samples

Sisal vegetable fibres from Kenya were cut to an average length of 3 – 10 mm and had a thickness of 0.2 – 1.0 mm. Portland cement type CEM I, 32.5R, was used for stabilization. Pictures of the sisal fibre are shown in figure 3.1

Fig. 3.1(a) Sisal Vegetable

Fig. 3.1(b) Sisal Vegetable

Addition of sisal, cement or sisal-cement to soil was done in ratios by weight of dry soil. In the first batch, compressed bricks were made by reinforcing the soil with 0.25, 0.5, 0.75, 1.0 and 1.25% sisal fibres. Portland cement in the following proportions: 5, 9 and 12% was used for stabilisation in the second batch. The third batch involved the use of both sisal and cement as shown by item 5 in table IV. In the final case, pressed soil blocks were made without cement stabilisation or sisal reinforcement. The summary of the sample fabrication compositions are shown in table 3.4. In total 24 mixtures were used. For every mixture, 8 full blocks were fabricated.

Mixing of cement, sisal or sisal-cement in soil was done by hand on a wheelborough in a dry state. The mixing was thoroughly done before water was added to sufficient workability. Addition of about 2% water above the optimum moisture content provided a composition that would gain adequate block density on drying.

TABLE IV
SAMPLE FABRICATION COMPOSITIONS

S. No.	Mix Composition, Wt %			Specimen Name
1	**Earth**	**Sisal**	**Cement**	
2	100	0	0	SC-0
3	100	0.25	0	SC-0.25
		0.5		SC-0.5
		0.75		SC-0.75
		1.0		SC-1.0
		1.25		SC-1.25
4	100	0	5	CeC-5
		0	9	CeC-9
		0	12	CeC-12
5	100	0.25	5	C-SC-5-0.25
		0.5		C-SC-5-0.5
		0.75		C-SC-5-0.75
		1.0		C-SC-5-1.0
		1.25		C-SC-5-1.25
	100	0.25	9	C-SC-9-0.25
		0.5		C-SC-9-0.5
		0.75		C-SC-9-0.75
		1.0		C-SC-9-1.0
		1.25		C-SC-9-1.25
	100	0.25	12	C-SC-12-0.25
		0.5		C-SC-12-0.5
		0.75		C-SC-12-0.75
		1.0		C-SC-12-1.0
		1.25		C-SC-12-1.25

Fig. 3.2 Sisal-soil mixing.

Fig. 3.3 “Balram” Block press
“Artifact gGmbH”

A manually operated constant volume press borrowed from “artifact gGmbH” of Glücksburg, Germany, shown in figure 3.3, was used for fabrication of compressed earth blocks. Although it was not possible to measure exactly the compaction pressure, numerous past researchers have indicated that such a single acting ram press is capable of developing pressures of between 2 – 4 MN/m^2. The press used in this investigation produces full blocks with nominal dimensions 230 mm (length) 110 mm (width) and 60 mm (height).

The sisal reinforced compressed blocks were extracted from the press and air dried in the open for a period of 28 days before being tested. The cement and sisal-cement blocks were cured under polythene sheeting for 14 days and moistened daily to allow for complete hydration of cement then left in the open to dry for another 14 days before testing for mechanical strength.

The equipment available for testing of both compressive and tensile strength, required prisms of the size 160 mm (length) 40 mm (width) and 40 mm (height). These smaller scale blocks were obtained by cutting the full blocks in a diamond coated rotary power cutter. Because of the diamond coat, it was possible to cut through the full bricks with high precision and without the risk of breakages. The rotary power saw model “WOCO-TOP 300-A2”, shown in figure 3.4, is manufactured by Conrad Apparetebau GmbH. Sample of compressed soil blocks are shown in figure 3.5.

Fig. 3.4 Blocks Cutting equipment.
“Conrad Apparetebau GmbH”,

Fig. 3.5 Sample Blocks

3.3 Experimental Setup for testing of Block Strength in the absence of laboratory facilities

In the proposed procedure, compression strength experiments are substituted through the so called “total dead weight experiments”, which can be held in the absence of the expensive laboratory equipment. Results of the loading experiments are then correlated to compression strength ones through a computed conversion factor. The overall procedure or concept is described by the scheme in figures 3.6 and 3.7

Total dead weight experiments are done by subjecting an earth block sample to a load until the sample raptures as shown in figures 3.8 and 3.9. A bucket is attached to the soil block sample by a string tied on the middle of the block. Sand is then poured into the bucket; this is done in batches of about 0.5 kg at intervals of approximately 1 minute up to the time the block sample collapses. The weight of the bucket and sand therein is taken and recorded. The process is repeated for all the 6 sisal – soil mix proportions illustrated in table 3.4.

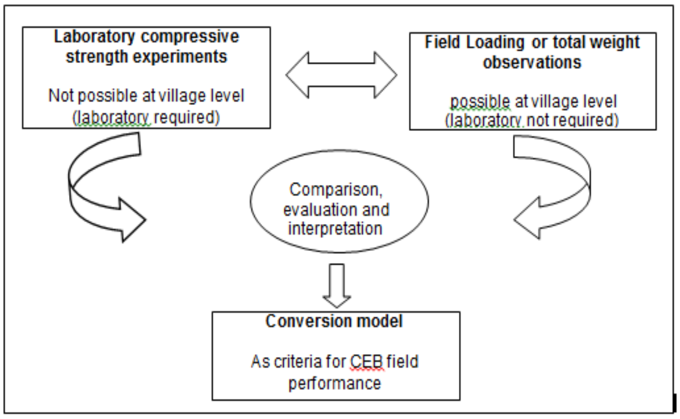


Fig. 3.6 Overall Concept of the conversion model.

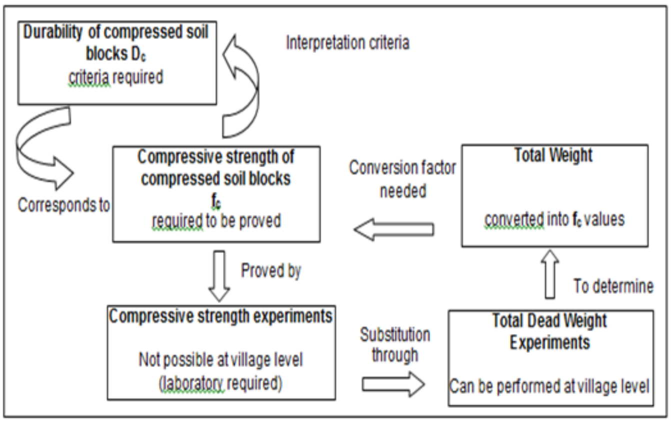


Fig. 3.7 Detailed concept of the conversion model.

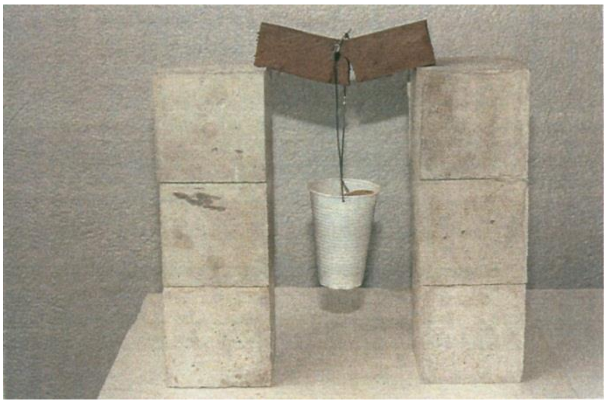
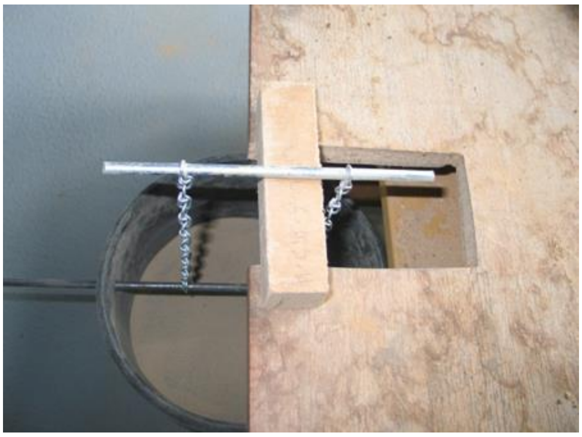


Fig. 3.8 Preliminary total dead weight experiments.

Fig. 3.9 (a) Total dead weight experiments



(b)

Fig. 3.9 (b) Total dead weight experiments

4. Results and Discussion

For each sisal-soil proportion, the weight required to bring the sample block to breaking or to rapture has been measured. Results for sisal-reinforced blocks are outlined in figure 4.1 and figure 4.2 as well as in table V and table VI. Change in the total dead weight with increase in sisal content is similar to change in compressive strength with increasing sisal levels, displayed in figure 4.1 and 4.2. This similarity in behaviour of the two trends provided the motivation to assume that a positive relationship between strength and total dead weight against sisal levels exists.

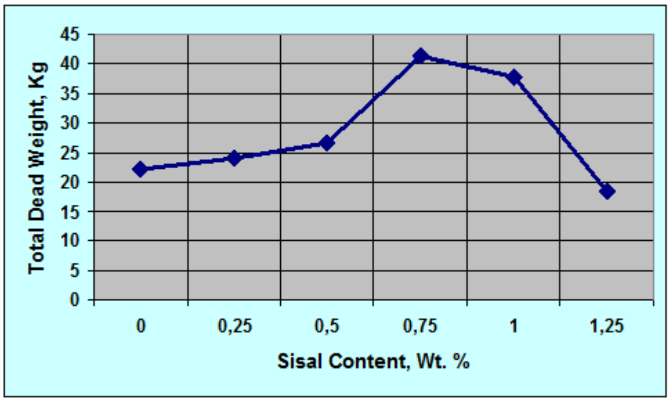


Fig. 4.1 Total dead weight as a function of sisal content

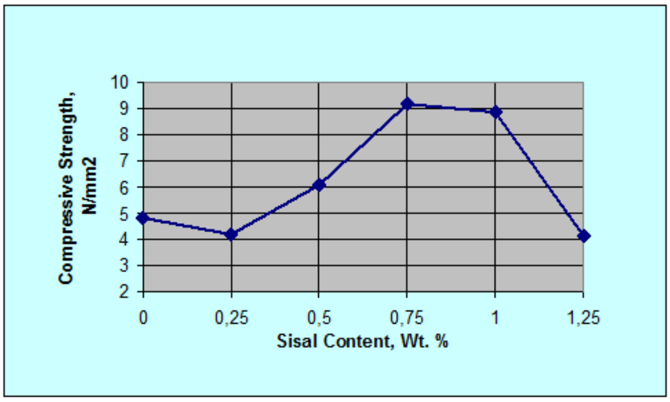


Fig. 4.2 Compressive strength as a function of sisal content.

Conversion Factor Model

A correlation is made between the compressive strength values denoted as y and the measurements of the total dead weight obtained at block rapture denoted as x. The correlation factor k_1 has then been obtained for each mix composition using equation 4.1. The correlation factor k_1 is found to lie between 4.365357 and 5.747085; a mean value of k_1 is computed to be 4.66 with a standard deviation of 0.546791.

$$Y \times K_1 = X \qquad 4.1$$

Equation 4.2 gives the established conversion model. This model can be applied by local people in the villages to evaluate the compression strength of manufactured earth blocks in the absence of laboratory facilities that would otherwise directly measure compression strength.

$$Y \times 4.66 = X \qquad 4.2$$

From investigations of the present work, it can therefore be deduced that:
Compressive Strength x 4.66 = Total Dead Weight

TABLE V
RESULTS OF THE TOTAL DEAD WEIGHT AGAINST COMPRESSION STRENGTH

Specimen Reference	**Compressive Strength, (y) N/mm^2**	**Ultimate Breaking Load,(x) Kg**	**Conversion factor, (k_1) $K_1 = x/y$**
SC-0	4.798	22.205	4.627247
SC-0.25	4.18	24.03	5.747085
SC-0.50	6.08	26.525	4.365357
SC-0.75	9.14	41.275	4.515247
SC-1	8.87	37.81	4.263284
SC-1.25	4.16	18.49	4.443376

A second correlation is made between the flexural strength values denoted as δ and the measurements of total dead weight obtained at block rapture denoted as β, table VI. The correlation factor k_2 is then obtained for each mix composition using equation 4.3. The correlation factor k_2 is found to lie between 21.75294118 and 32.04, a mean value of k is computed to be 25.4747 with a standard deviation of 3.65

TABLE VI

RESULTS OF THE TOTAL DEAD WEIGHT AGAINST FLEXURAL STRENGTH

Specimen Reference	Flexural Strength, δ N/mm^2	Ultimate Breaking Load,(β), Kg	Conversion factor, (k_2) $K_2 = β/δ$
SC-0	0.992	22.205	22.38407258
SC-0.25	0.75	24.03	32.04
SC-0.50	1.035	26.525	25.62801932
SC-0.75	1.63	41.275	25.32208589
SC-1	1.47	37.81	25.72108844
SC-1.25	0.85	18.49	21.75294118

$$\delta \times k_2 = \beta \qquad (4.3)$$

Equation 4.4 hence gives the established conversion model with respect to the flexural strength, thus:

$$\delta \times 25.47 = \beta \qquad (4.4)$$

It can therefore be deduced that:

Flexural Strength x 25.47 = Total Dead Weight

A more accurate interpretation of the model with respect to compressive and flexural strength is given in figure 4.3a and figure 4.3b respectively.

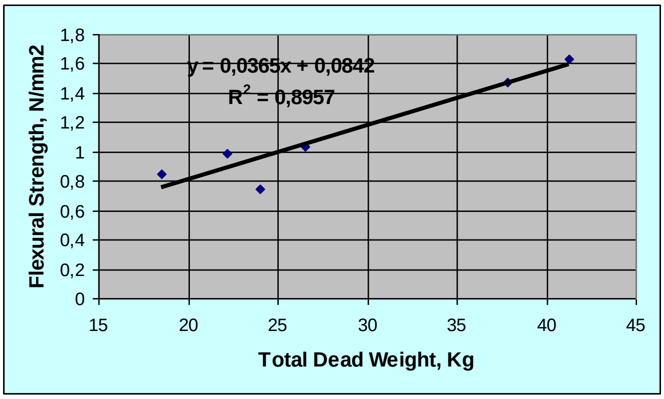


Fig. 4.3a Flexural strength against total dead weight

Fig. 4.4b Compressive strength against total dead weight

According to Walker [20], who has done extensive research in the area of compressed earth blocks, total dead weight tests are more reflective of the flexural (modulus of rapture) strength than to compressive strength; based on this, equation 4.4 would be more recommended for application as the conversion model.

5. Conclusion

A model to correlate standard testing procedure of compressive and flexural strength and quality testing method in the absence of laboratory facilities has been developed. This is with respect to compressed earth blocks reinforced with sisal fibres. It has been established that the total dead weight is 47.25 times the Flexural Strength while the same is 66.4 times the Compressive Strength. The primary advantage of the proposed method is that it can easily be adapted at village level by people who have little scientific knowledge.

Acknowledgement

Several members of Brandenburg Technical University Cottbus (BTU) gave me great support. Prof. Dr.-Ing. Wolfgang Spyra and Prof. Dr.-rer. nat., habil. Ing. Reinhard Frey provided great scientific guidance to this project; I wish to express my very sincere gratitude to them. Frau Dr.-Ing. Angelika Mettke constantly directed and supervised my work with great dedication; without her financial involvement, this project would not have taken place. My very deep appreciation goes to Dr.-Ing. Christian Stollberg from the Chair of Mineral Processing at BTU for constantly being with me at the hour of need, for his academic and financial assistance, throughout the time I researched and wrote this piece of work. I appreciate the kindness of Prof. Dr.-Ing. habil. Peter Ay; he allowed me unlimited access to his laboratories without any financial reciprocation.

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