NJCTM VOL. 2 NO. 1 JULY 1999

Preliminary Study of the Properties of Compressed Straw Slabs

OG Okoli, JA Apeh and M M Garba
Department of Building, Ahmadu Bello University, Zaria, Nigeria

The physical and mechanical properties of compressed straw slabs were investigated. The straw slabs were produced using two types of binders: Gum Arabic and Portland Cement mixed in the ratio of 30% rice straw and 70% binder. A manual screw pressing machine with a maximum capacity of $0.13N/mm^2$ was constructed used for the pressing of the slabs. The properties of the slabs measured were Density, Moisture content, Conductivity and Modulus of Rupture (bending strength). The results obtained were compared with the data available in the standards and with the results of previous researchers. The average values obtained for the slabs using Gum Arabic and Portland Cement binders respectively are as follows: The average maximum and minimum values obtained were as follows: Density (ρ) -425.5Kg/m^3 and 303.2Kg/m^3, Moisture content (M_c) -8.61% and 5.26%, Conductivity (K)-0.035W/M°C and 0.025W/M°C, Modulus of rupture (S) - 0.33N/mm^2 and 0.20N/mm^2. All the samples passed the tests successfully except the moisture content test. In general, the results obtained showed that rice straw is a potential material for the production of compressed straw slabs.

INTRODUCTION

Compressed straw slabs are defined by BS 4046: 1971 as "straw compacted only by heat and pressure, surfaced and bound at the edges with paper with or without an added bonding agent. It has a density of 365Kg/m^3, thermal conductivity of 0.01W/M°C and spread of flame of class 3 and thickness between 49mm and 53mm". Principally, straw slabs are used for partitions, thermal insulating boards (ceiling boards) and sometimes as permanent shuttering to concrete elements. Agricultural waste products form the bulk of the raw material used for the production of straw slabs. Such locally available materials include rice husks, groundnut shells, maize cobs and bagasse etc (Oguntuase, 1977 and Apeh, 1998).

The use of straw slabs as wall materials started long ago. Bainbridge et al (1989) traced the historical use of straw slabs (known as straw clay) from late 1800 in the United States of America. It has a density of between 300 - 1200Kg/m^3 depending on the degree of compression and the ratio of straw to clay. It has high thermal and sound insulating capacity.

Herlitz et al (1984) at the Royal Institute of Technology Stockholm produced cement-bonded straw slab using wheat straw. The straw was soaked in water for two days and then mixed with dry cement in a mix proportion of 30% straw and 70% cement and compressed using hydraulic press of 5KN/m^2. It has a thermal conductivity of between 0.07W/M°C - 0.08W/M°C and good fire resistance but no test was conducted to determine its flexural strength.

Furthermore, Salas et al (1986) at the Institute E Torroja de la Construction Y del Cemento, Madrid, produced cement-bonded rice husk straw slab. the rice husks were soaked in a 5% lime solution for 24 hours and then mixed with a cement slurry with water/cement ratio of 0.75. the weight proportion of rice husks to cement was between 28-72%. The slabs have density of 824Kg/m^3, and flexural strength of 0.92N/mm^2 and thermal conductivity of 0.08W/m°C. Other related slabs include the wood wool slabs. This type of slab is normally manufactured using spruce or other kinds of wood. The wood wool is soaked with calcium chloride, pre-pressed and then mixed with cement and finally compressed and left to harden for 24 hours. It is then stripped, trimmed and cured for 2 - 3 weeks. It has good acoustic and insulation properties, while the conductivity ranges between 0.08 - 0.013 W/m°C.

In a recent study, Hermansson (1993) at the Lund Centre for Habitat Studies, Lund University Sweden produced straw slab using wheat straw and cement slurry as binder. The materials were thoroughly mixed and compressed in a mould using hydraulic press of maximum capacity of

$0.5KN/m^2$. It was left to harden for 24 hours and then stripped, trimmed and cured for 2 weeks. The density of the slabs was between 200 - $500Kg/m^3$. The flexural strength was between 0.25 - $0.46N/mm^2$ and thermal conductivity of between 0.12 - 0.47W/m°C.

TEST MATERIALS

Straw

The straw used for the study is rice straw of the variety Oryza Sativa Linn otherwise known as the short variety. It was obtained from farms in Samaru, Zaria. Two types of binders were used in this research namely Portland Cement and Gum Arabic.

Gum Arabic

This is a hard substance obtained through incision on the trunk of the tree, Acacia Senegalis. It is commonly found in the northern part of Nigeria and other parts of Africa like Senegal, Tunisia, Libya and Tanzania. Chemically, it consists of compounds of neutral salts such as potassium, magnesium or calcium of acidic polysaccharides (Encyclopaedia Britannica 1975). It was produced and obtained from Birnin Kebbi, Kebbi State, Nigeria. Being in pebbles, it was ground into powder using mortar and pestle and sieved using 300 μm sieve to facilitate disolveability and to prevent lumping in the mixture.

Cement

The cement used is the ordinary Portland Cement (Ashaka brand) produced in Nigeria. The quality used met the minimum requirement for soundness and setting time as specified in BS 12 (1978).

Production of Rice Straw Slab

The rice straw washed and dried. The required quantity was weighed and pounded. To reduce the effect of carbohydrate which may hinder adequate bondage of straw and binder, the straw was soaked for forty eight hours in a solution of 5% sodium chloride per 100 litres of water. The straw was then spread and allowed to dry to an average moisture content of 10 - 14%. (Hermansson 1993) Trial mixes arrived at the decision to use 30% straw and 70% binder. It was found that this combination gave the best cohesion between the straw and binders.

BS 4046 (1971) provides that dimensions of the straw slab should be as follows:

Length 1800 - 3600mm
Width 1197 - 1200mm
Thickness 49 - 53mm and
Density 340 - $440Kg/m^3$.

For the purpose of this study and in order to have a portable mould, it was decided to adopt a mould of dimensions 400 x 400 x 50mm. This was used in the mat formation. The mat was filled with the straw and thoroughly mixed with the binder and levelled with a trowel. It was lightly compacted using wooden straight edge over the surface. The bottom and sides of the mould was normally rubbed with oil to ease demoulding. The press used for this study was locally fabricated. The principle of its operation is the same as the hydraulic jack. The pressing pad which is few millimetres less than the dimension of the mould is operated using a threaded lever located at the centre of the pad. Pressure is applied to slabs by gradually rotating the lever until it presses tightly on the mat. The arrangement is left in this position for one week demoulded and left to cure at room temperature. The slabs were cured in cool dry condition for 30 days. This is necessary so as to equalise the moisture content throughout the slab and to minimise warping that may occur.

TESTS OF SPECIMEN

Determination of Density

The density of the specimens were determined in accordance with Appendix B, BS 4046 1971. The length, breadth and thickness of the specimens were measured to nearest 1.5mm with the aid of callipers.

Each specimen was weighed and the weights recorded. The density of each specimen was obtained using the relation $\rho = M/V$

Where ρ = Density of specimen (Kg/m^3)
M = Mass of specimen (Kg)
V = Volume of specimen (m^3)

The calculated results are presented in Table 1.

Moisture Content

The specimens were weighed and then dried in a ventilated oven at a temperature of 103°C until the weight is constant between two consecutive weightings made at an interval of not less than one hour. The moisture content expressed as a percentage of the oven-dry weight is given by the following expression:

Where $M_c = [(W_1 - W_o)/W_o] \times 100$
W_1= Initial weight in grammes
W_o=Oven-dry weight in grammes
M_c= Moisture content of the sample

The calculated results are shown in Table 2.

Thermal Conductivity

This is defined as the rate of heat passage across a material per unit per °C between faces of the material. An adopted version of the Lee Disc apparatus was used for the measurement of thermal conductivity. Theoretically, if Q is the rate of heat flow between two surfaces then: Q varies directly as the temperature difference $(T_2 - T_1)$.

Q varies directly as the area, A (mm^2)
Q varies indirectly as the thickness, t (mm).
Hence $Q = (KA)/t\,(T_2 - T_1)$ Watts (1)

Where K is a constant called the thermal conductivity of the material. The calculated results are presented in Table 3.

Modulus of Rupture

The specimens were placed on the rollers and with the aid of lead balls, loads are gradually applied at the centre. The loads were gradually increased until the specimen fails. The failure loads were determined on the scale and the values recorded. The modulus of rupture was calculated using the expression given in BS 1142, Part I, 1971 as follows:

Where $S = (3pl)/(2bt^2)$
S = Modulus of rupture (N/mm^2)
p = Load at rupture (N)
l = Distance between supports (mm)
b = Width of specimen (mm)
t = Thickness of specimen (mm).

A total of 144 samples were tested. The results are shown in Table 4.

DISCUSION OF RESULTS

Density

From Table 1, the average densities of the slabs were $303.2Kg/m^3$ and $425.5Kg/m^3$ for the slabs using Gum Arabic and cement binder respectively. Portland Cement has a higher density than Gum Arabic hence it is expected to produce slabs of higher density. BS 4046 (1971) recommends that densities of straw slabs should be within $330.2Kg/m^3$ and $440.5Kg/m^3$. Hermansson (1993) produced similar slabs with densities ranging from $200.2Kg/m^3$ and $500.5Kg/m^3$.

Moisture Content

From Table 2, the average moisture contents were 8.61% and 5.26% for slabs with Gum Arabic binder and cement respectively. The higher value for moisture content for slabs with Gum Arabic binder may be attributed to its low density hence more void through which more moisture is absorbed. Compared with range of value specified in BS 4046 (1971), the moisture content values for both straw slabs are not within the specified range (14 - 20%) However, the result obtained for the slab using Gum Arabic as binder is encouraging, however more experience is needed for subsequent better results.

Thermal Conductivity

The average values obtained were 0.035W/m°C for slabs with Gum Arabic binder and 0.025W/m°C for cement bonded slabs (Table 3). The higher value of thermal conductivity for slabs with Gum Arabic binder can be attributed to its higher moisture content.

There is no specified range of conductivities for building materials in the Code of Practice, but it was found that similar materials (woodwool) is between 0.075W/m°C and 0.125W/m°C.

Modulus of Rupture

From Table 4, the average values recorded for the Gum Arabic and Portland Cement bonded slabs were $0.33N/mm^2$ and $0.29N/mm^2$. This indicate that Gum Arabic bonded slabs have a higher ability to support load compared to cement bonded slabs. This may be attributed to the fact that cement did not readily bond with rice straw due to the high carbohydrate content which may not have been thoroughly removed before mixing with cement.

However, the results obtained using both binders compares favourably with the values of previous researchers. Hermansson (1993) obtained values ranging from $0.25N/mm^2$ to $0.46N/mm^2$ for slabs of densities between 300 - $500Kg/m^3$. Salas et al (1986) obtained an average value of $0.92N/mm^2$ by using hydraulic press. German and Austrian Standards for wood wool slabs specify flexural strength of $0.45N/mm^2$

Relationship Between the Measured Properties

Thermal Conductivity and Density

This is shown in Figure 1. The results for both slabs show an increase in conductivity as density increases. For Gum Arabic bonded slabs, a maximum density of 440Kg/m^3 has a corresponding thermal conductivity of 0.05W/m°C. For the cement bonded slabs, a maximum density of 440Kg/m^3 has a corresponding conductivity of 0.05W/m°C. These values meet the standard specification of the Food and Agricultural Organisation Specification F.A.O.S: 1963 which stated that for slabs of density 300 - 400Kg/m^3, the thermal conductivity should be between 0.06 and 0.071W/m°C.

Thermal Conductivity and Moisture Content

The graph of thermal conductivity against moisture content for both slabs show a significant increase in conductivity as moisture content increases (Figure 2). For Gum Arabic bonded slabs, a maximum moisture content of 12% gives a conductivity of 0.072W/m°C while a cement bonded slab with a moisture content of 12% has a thermal conductivity of 0.09W/m°C. These results agree well with F.A.O.S Standard, which specify thermal conductivity of plywood and other wood slabs between 0.06 - 0.071W/m$_0$C at maximum moisture content of slabs between 10 - 12%.

Modulus of Rupture and Density

Figure 3 shows the relationship between modulus of rupture and density. For the Gum Arabic bonded slabs, a maximum density of 440Kg/m^3 has a bending strength of 0.33N/mm^2 while a cement bonded slab with the same density has a bending strength of 0.29N/mm^2. In his work, Hermansson (1993) produced slabs of the range of densities having modulus of rupture between 0.25N/mm^2 and 0.46N/mm^2.

F.A.O.S (1963) specify that the values for modulus of rupture 1.0N/mm^2 to 7.4N/mm^2 for densities ranging between 300 - 400Kg/m^3. In comparison with F.A.O.S, the slabs are below the specification. However, it should be noted that the technology of production is not the same. The capacity of the press in particular is low and need to be increased and improved.

CONCLUSION AND RECOMMENDATIONS

In this preliminary report, the physical properties of rice straw slabs using Gum Arabic and Portland Cement as binders are presented. The physical properties studied are density, moisture content, conductivity, and modulus of rupture. From the results obtained so far, only moisture content gave unsatisfactory result while the other properties satisfied the minimum values set forth in the standards for straw slabs.

Consequently, rice straw could be considered a suitable material for the production of compressed straw slabs.

Table 1: Density of the Compressed Straw Slabs

SLAB NO	DENSITY (Kg/m^3)	SLAB NO	DENSITY (Kg/m^3)
GUM ARABIC		PORTLAND CEMENT	
1	215.56	19	387.36
2	332.82	20	392.19
3	326.67	21	402.62
4	310.55	22	390.15
5	330.25	23	376.94
6	215.00	24	428.43
7	325.12	25	402.75
8	328.50	26	403.40
9	245.25	27	443.59
10	365.04	28	445.00
11	391.08	29	465.78
12	394.00	30	487.93
13	201.00	31	390.15
14	250.25	32	403.39
15	225.35	33	393.51
16	300.18	34	486.95
17	325.42	35	466.08
18	275.25	36	493.39
Average Density =303.17 Kg/m^3		Average Density = 425.53Kg/m^3	

Table 2: Moisture Content of the Compressed Straw Slabs

SLAB NO	MOISTURE CONTENT	SLAB NO	MOISTURE CONTENT
GUM ARABIC		PORTLANDCEMENT	
1	6.0%	19	1.22%
2	9.1%	20	2.50%
3	6.8%	21	3.78%
4	5.96%	22	2.25%
5	8.07%	23	1.06%
6	5.96%	24	5.0%
7	6.43%	25	4.0%
8	7.34%	26	5.15%
9	11.67%	27	7.81%
10	13.64%	28	8.33%
11	13.88%	29	2.67%
12	14.94%	30	4.17%
13	4.96%	31	7.30%
14	5.0%	32	4.17%
15	12.0%	33	3.52%
16	6.06%	34	8.72%
17	7.75%	35	8.05%
18	10.0%	36	8.82%
Average Moisture Content = 8.61%		Average Moisture Content = 5.26%	

Table 3: Thermal Conductivity of the Compressed Straw Slabs

SLAB NO	Thermal Conductivity w°C	SLAB NO	Thermal conductivity w°C
GUM ARABIC		PORTLANDCEMENT	
1	0.027	19	0.012
2	0.037	20	0.018
3	0.030	21	0.020
4	0.025	22	0.015
5	0.036	23	0.010
6	0.029	24	0.022
7	0.034	25	0.020
8	0.036	26	0.021
9	0.040	27	0.023
10	0.049	28	0.028
11	0.050	29	0.037
12	0.051	30	0.020
13	0.020	31	0.076
14	0.020	32	0.021
15	0.042	33	0.019
16	0.028	34	0.034
17	0.035	35	0.031
18	0.038	36	0.035
Average Thermal Conductivity = 0.035w/m°C		Average Thermal Conductivity = 0.025w/m°C	

Table 4: Modulus of Rupture of the Compressed Straw Slabs

SLAB NO	Bending Strength (N/mm^2)	SLAB NO	Bending Strength (N/mm^2)
GUM ARABIC		PORTLAND CEMENT	
1	0.25	19	0.23
2	0.30	20	0.26
3	0.29	21	0.28
4	0.28	22	0.25
5	0.29	23	0.20
6	0.24	24	0.30
7	0.30	25	0.28
8	0.48	26	0.28
9	0.33	27	0.32
10	0.38	28	0.33
11	0.45	29	0.35
12	0.55	30	0.37
13	0.18	31	0.25
14	0.28	32	0.28
15	0.25	33	0.27
16	0.46	34	0.37
17	0.33	35	0.35
18	0.35	36	0.38
Average Bending Strength = 0.33N/mm^2		Average Bending Strength = 0.29N/mm^2	

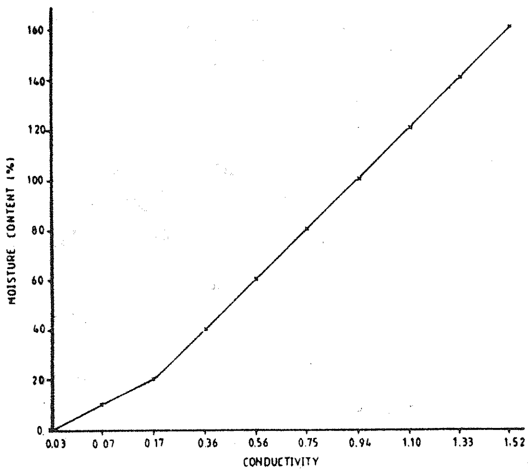

Fig. 2: Thermal Conductivity and Moisture Content

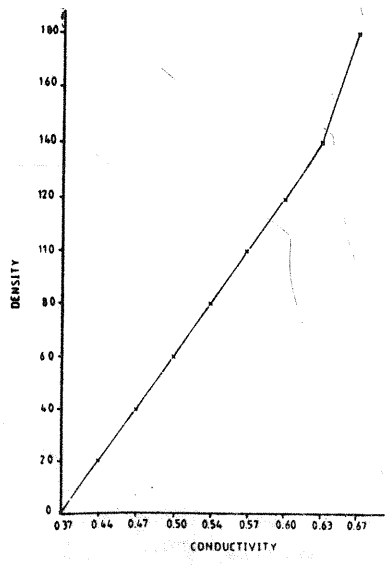

Fig.1: Thermal Conductivity and Density

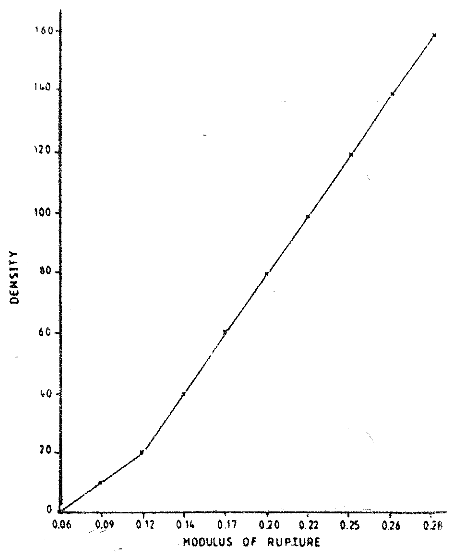

Fig. 3: Modulus of Rupture and Density

REFERENCES

1) Apeh, J.A. (1998) The Use of Rice Straw in the Production of Compressed Straw Slabs. Unpublished M.Sc thesis, Department of Building, ABU, Zaria.

2) Bainbridge, D.B. et al (1989) Plastered Straw Bale Construction. The Canelo Project, Canelo, Arizona. Pg 4.

3) BS 4046 Parts I & II - Specification of Compressed Straw Building Slabs, BSI, 1969 and 1971. London

4) B.S 12 Part I Specification for Portland Cement. B.S.I (1978) London

5) B.S 1142 Part I Specification for fibre Building Board. BSI, (1971) London

6) Encyclopaedia Britannica (1975) Vol 10 pp 1084. Encyclopaedia Britannica Inc. London.

7) Food and Agriculture Organisation Specifications (F.A.O.S) F.A.O Report on Plywood and Other Wood-Based Panels. 8th - 9th July 1963.

8) Herlitz, B. and Glen, K. (1984) Study of Cement-Bonded Straw. Masters Thesis, Royal Institute of Technology, Stockholm, Sweden. Pp 21 - 22.

9) Hermansson, L.A. (1993) Cement-Bonded Straw Slabs. (A Feasibility Study) Building Issues 5(2) LCHS, Sweden.

10) Oguntuase, B.J. (1977): The Suitability of Producing Particle Boards from Groundnut Shells in Nigeria, ABU, Zaria. Unpublished M.Sc thesis.

11) Salas, J. and Janer, V. (1986) Insulating Panels with Rice Husk Housing Science, USA.