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COMPRESSIVE STRENGTH TESTING OF PLASTERED STRAW BALE

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ABSTRACT

This paper is a presentation of compressive strength testresults on plastered straw bale block. Guinea corn – straw fiber were baled and plastered with mortar into straw bale blocks of fibers with an average of 6mm thickness, 11.2% moisture content, and baled at a density of range between 0.161 - 0.190 kg/ mm^2. The fiber blocks were subjected to vertical loading on different plaster thickness of 10, 15 and 20mm using 1:3, 1:4 and 1:6 mix proportion of cement to sand. The results showed that the maximum compressive strength of 6.046 $N/mm^2$was obtained with amix ratio 1:3 and 20mm plaster thickness, while the minimum compressive strength of 1.698 $N/mm^2$was obtained with a 10mm plaster thickness which meet the requirement of standard compressive strength of sand Crete block (1.8 - 2.5 N/mm^2) stipulated by the British standard (BS 6073).

Keywords*: *Compressive Strength Testing, Plastered Straw Bale Block, Guinea Corn, Mix Proportion.

I. INTRODUCTION

1.1 Background of the Study

The need to construct buildings with viable low cost material has become a necessity in our fast growing society. It goes without saying that the growing population of Nigeria (most populous black nation on earth) and the escalating cost of conventional building materials that are around 20-30% higher than what is obtainable in the West African sub region and other parts of the world, in addition to the rather high average inflation level of 12.6% as reported in January 2012. Thus, the high cost of conventional building materials has become a major source of problems in the housing sector. With this in mind, there is need to adopt cost effective construction methods either by upgrading of traditional technologies using local resources or applying modern construction materials and techniques with efficient inputs that will lead to economic solution (Punch 18th March, 2012).

1.2 Problem Statement

Nigeria as the most populous leading Black Country in the world has a high housing deficit that currently stands about 16 million units due to high costs of acquiring land and conventional building materials (Punch 18th March, 2012). Because of these problems, there is need for alternative low cost building materials; like agricultural waste products e.g. straws that readily available, affordableand have the potential to significantly reduce the housing deficit.

II. METHODOLOGY

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2.1 Specimen Description and Production of Straw Bale Block

The following sections describe the materials and production of the straw bale block specimens. Several of the terms used are specific to this type of production of straw bale and care has been taken to ensure their proper context or provide a definition. Example, like 150mm cube block was selected for the research.

2.1.1 Specimen Description

Wooden mould of different sizes based on the plaster thickness were constructed for moulding the straw bale block specimen with at least two (2) identical mould for each plaster thickness. The mould sizes are as follow; -

- For 10mm plaster thickness - 130× 130 × 130mm.
- For 15mm plaster thickness - 120× 120 × 120mm.
- For 20mm plaster thickness - 110× 110 × 110mm.

Figure 2.1: Wooden Mould of Straw Bale.

2.1.2 Selection of Materials

Straw: A dry guinea corn (straw) sourced from a farm near A.T.B.U (Sabon Kaura Village), were used as a straw materials throughout this research. The straws were clean, free from debris and other leaves, and purchased at a low price of #200 naira per bundle and supplied to the school where it was left in open space to naturally dry for use.

Figure 2.2: Straw Bale Samples.

Fine aggregate: In production of straw bale block, material like fine aggregates which was clean, naturally sharp, and well graded (free from salts, chalk and clay) of about 100% passing through sieve no. 5mm was chosen and employed in the mix which conform to **BS 410** and itstest was carried out in accordance with the procedure given in **BS 810-1:1975, 882:1992.**

Cement: An ordinary Portland cement named as Ashaka cement was selected and employed in the plaster mix of the straw bale.

Water: An amount of water fits for drinking, clean, free contaminant, and free from organic matter coupled with any dissolved or suspended solute which could affect the plaster strength adversely, was employed in the plaster mix of the straw bale.

2.1.3 Straw Bale Preparation

The straw bales used in this experiment were one (1) string guinea corn bales. The bales were specifically tested and noted with its average moisture content equal to 11.2%, and kept in a good condition for ready use.

Cutting: The straws (guinea corn) were cut according to sizes stated in a specimen description by means of hand cutting (knife), and rip saw in order to fit the selected moulds of straw bale employed in the research.

Baling and compressing of straw: The cut straws were placed into their respective moulds sizes and compressed by mean of manual-fly (wing) pressing machine as a substituted of baling machine, since its not reputed to be available in Nigeria and it tightly bounded with binding wire (string) to come up with bale edge laid flat. The bales were varied in mass and dimension in order to represent light, medium, and heavy density of straw bales used for the research, (see Table 3.1- 3.3). And the whole process were adopted and repeated for each numbers of mould size required.

Figure 2.4: Baling of Straw Using Manual Compressing Machine (wing/fly)

2.1.4 Particle Size Distribution

Commercially available clean, natural sharp sand (free from salt, chalk and clay) of 100% passing sieve no. 5mm and which complies with **BS 812, 882:1201** was employed as a maximum fine aggregate to the straw bale plaster mix. The sieves used are: **-** 5mm, 2.36mm, 1.18mm, 600μm, 300μm, and 150μm with weight of sample equal to 300g. The grading test results are shown in (Table 3.4) for the determination of the distribution of different sized particle present in the sample employed for the production of plastered straw bale block.

2.1.5 Skin Material of the Straw Bale

The skin material employed was cement plaster which starts as dry matrix that is mixed of cement, fine aggregate with water added to it, to forms paste which liberate heat and then harden. The cement plaster skin was selected to work together with the straw bale in order to function as a skin panel resisting compressive load.

2.1.6 Plaster Mix Proportion

The plaster mix employed in this research has been designed based on the American concrete institute mix design (ACI) method. The proportion proposed were 1:3, 1:4 and 1:6 ratios with a water cement ratio of 0.5, 0.5 and 0.55 respectively by weight. The mix designation and quantities of various material for each plaster mix proportion have been tabulated in (Table 3.5) for cube mould size.

2.1.7 Batching, Mixing, Moulding and Curing of Straw Bale Block Specimen

In moulding the block, after cement and fine aggregate have been acquired based on plaster mix proportion, a thorough mixing was done for the mix, this was then poured into an oiled steel mould say to the nearest 3mm increment above the selected plaster thickness (10, 15 and 20mm) for compaction, then the guinea corn straw bale which has been baled and ready for use, was placed into the mould and filled up with mortar which is then chucked and compacted by means of trowel and ply wood respectively.

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that, these were demoulded with care so that no edges were broken and placed into the curing tank at the ambient temperature ($27 \pm 2°C$) for curing of twenty eight (28days) in which the first three days were very important until sufficient strength were gained at 28 days.

Figure 2.5: Straw bale being moulding based on plaster thickness.

2.2 Water Absorption Test of the Plastered Straw Bale Block Specimen

The whole procedure of water absorption test was adopted in accordance with the **BS 1881-122: 1983** with age of specimen equal to 28 days. The measured water absorption of each specimen was calculated as an increase in mass resulting from immersion in water that expressed as a percentage of the mass of the dry specimen. Mathematically expressed as:-

$$\text{Water absorption, \%} \quad \% = \frac{M - M_f}{M_f} \times 100\% \quad \text{Eq. (1)}$$

Where: - M = Weight of specimen before curing, and

M_f = Weight of specimen after curing.

2.3 Compressive Strength Test of Plastered Straw Bale Block Specimen

Compressive strength test was conducted on plastered straw bale block specimens. The machine was first calibrated with maximum vertical load of pace/loading rate equal to 0.4 KN/s which is in accordance with the **BS-EN 1015-11:1999** (Table B.1**-** suggested loading rate of mortar) was applied to each block specimen and the machine was kept sufficiently stiff in flexure to ensure that the top and bottom of the panel were restraint against rotation. Eighteen (18) plastered straw bales were tested and noted with their modes of failures, in order to assess the compressive strength of bales plastered flat on edge.

In addition, plaster strength (mix ratio) and thickness were varied in order to determine their effects on the strength of individual plastered straw bales in compression. Each category of plaster was repeated twice (2 times) in order to understand the variability of the results. Experiment was also conducted on un plastered straw bale laid flat on edge, in order to determine how the straw bale alone behaves when loaded. Table (3.7) summarizes the compressive strength results.

2.3.1 Mode of failures

Figure 2.6: Plastered Straw Bale Under Compression and its Mode of Failures.

III. TEST RESULTS AND DISCUSSION

3.1 Results on Plastered Straw Bale Block Specimen

The lab tests were adequately described above in the protocol of methodology chapter and the samples were tested at 28days age of curing with respected to their different mix proportions and plaster skin thickness. Thus, the laboratory results obtained from the tests were presented in the following subsections.

3.1.1 Tests on Guinea Corn Fibres

Prior to testing, the following properties of guinea corn were obtained and details of the tests were shown in the appendix

QUANTITY	VALUE	UNIT
Moisture content, w	11.2	%

Young Modulus, E	15985	Mpa
Tensile strength, σ_t	126 – 911	Mpa
Extension, Δl	0.1030 - 0.7410	Cm

3.1.1.1 Unit Density of the Straw Bale Block Specimens

The dry unit density of straw after it has been baled into different dimension for each plaster thickness was determined by dividing its unit mass (Kg) with straw bale volume (mm^3). The results obtained were computed in the Table (3.1), (3.2) and (3.3) for the mix proportion of cement to sand-1:3, 1:4 and 1:6 respectively.

Table 3.1: Straw Bales Density for 1:3 Mix Proportions.

Serial No	Plaster Thickness (mm)	Bales Dimension (mm)			Specimen Mark.	Mass (Kg)	Average Mass (kg)	Volume $\times 10^6$ (mm^3)	Density (Kg/mm^3)
		Length	Breadth	Height					
1.	10	130	130	130	A10	0.20	0.39	2.20	0.175
					A12	0.19			
2.	15	120	120	120	B20	0.30	0.30	1.73	0.171
					B22	0.30			
3.	20	110	110	110	C30	0.22	0.48	1.33	0.180
					C32	0.26			

Table 3.2: Straw Bales Density for 1:4 Mix Proportions.

Seria	Plaster	Bales Dimension (mm)	Specime	Mas	Averag	Volum	Density

l No	Thickness (mm)	Length	Breadth	Height	n Mark.	s (Kg)	e Mass (kg)	e $\times 10^6$ (mm^3)	(Kg/mm^3)
1.	10	130	130	130	A20	0.36	0.39	2.20	0.180
					A22	0.41			
2.	15	120	120	120	B30	0.27	0.29	1.73	0.170
					B32	0.30			
3.	20	110	110	110	C10	0.24	0.25	1.33	0.190
					C12	0.26			

Table 3.3: Straw Bales Density for 1:6 Mix Proportions.

Serial No	Plaster Thickness (mm)	Bales Dimension (mm)			Specimen Mark.	Mass (Kg)	Average Mass (kg)	Volume $\times 10^6$ (mm^3)	Density (Kg/mm^3)
		Length	Breadth	Height					
1.	10	130	130	130	A30	0.34	0.35	2.20	0.161
					A32	0.36			
2	15	120	120	120	B10	0.32	0.32	1.73	0.180
					B12	0.32			
3	20	110	110	110	C20	0.23	0.24	1.33	0.185
					C22	0.24			

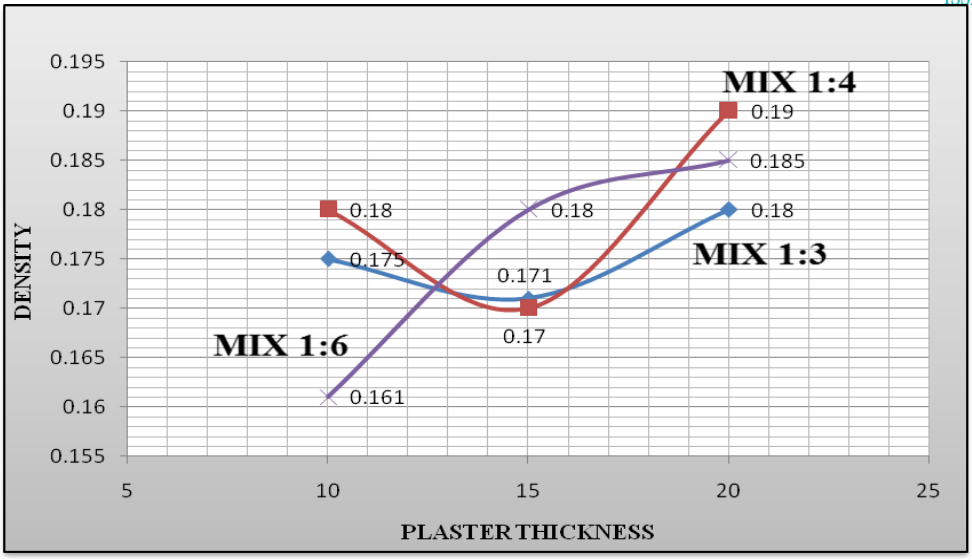

Figure 3.1: Unit Density versus Plaster Thickness of Straw Bale.

From Figure3.1 above, it was found that the density of straw bale for mix 1:6 behaves in a linear curve shape that is, its increases as the plaster thickness increasing, while densities of straw bale for mix 1:4 and 1:3 behave in a manner of falling and rising (non linearity) curve with maximum density obtained at maximum plaster thickness (20mm) employed in the research.

3.1.2 Particle Size Distribution

A nest of sieves is prepared by stacking test sieve one above the other with the largest opening at top followed by sieves of successively smaller openings and a catch pan at bottom. Opening mesh sizes of the sieves and sample used were shown and evaluated by standard sieve analysis in the methodology protocol and the result of grain size characteristic of the sample was predominantly pure fine aggregate with smooth s-curve shape as shown in the Table (3.4) and Figure3.2 below.

Table 3.4: Grading of Sand for Straw Bale Block.

S/No.	Sieve size (mm)	Mass retained (g)	Percentage retained (%)	Percentage passing (%)	Cumulative % retained
(0)	> 5mm	0.00	0.00	100.00	0.00
(1)	5.00mm	7.00	2.33	97.67	2.33
(2)	2.36mm	23.00	7.67	90.00	10.00
(3)	1.18mm	37.00	12.33	77.67	22.33
(4)	600μm	90.00	30.00	47.67	52.33
(5)	300μm	120.00	40.00	7.67	92.33
(6)	150μm	20.00	7.67	0.67	99.33
(7)	Pan	2.00	0.67	-	-
				$\sum$ F	278.65

Fineness modulus of fine aggregate $= \sum F/100 = 278.65/100$

= 2.787

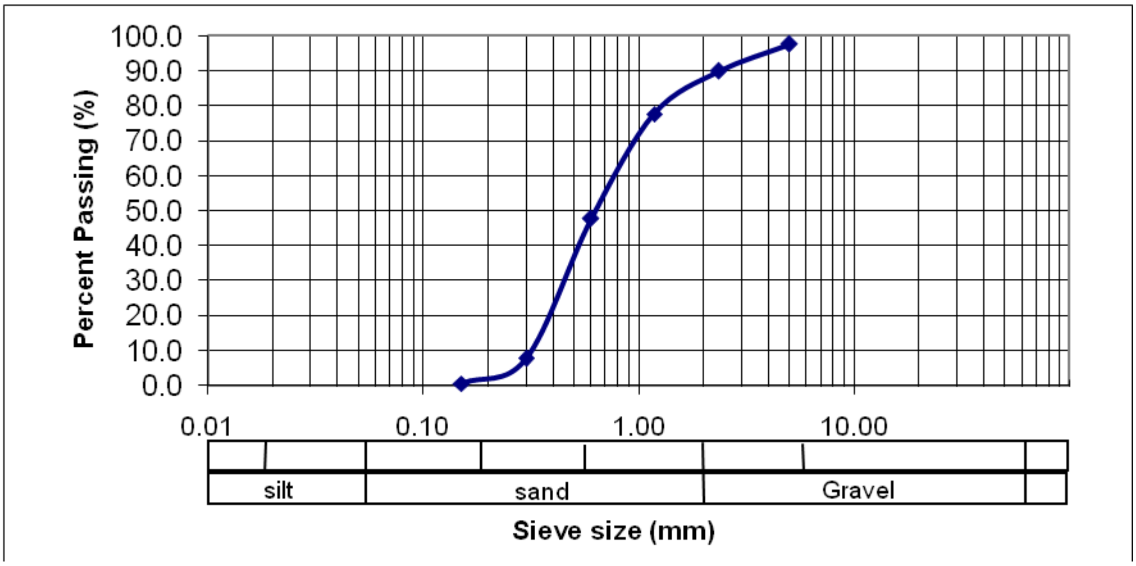

Figure 3.2: Grading of Sand for Straw Bale.

3.1.3 Mix Proportion

An amount of 0.5 and 0.55 water/cement ratios were used in the mixes in order to provide a means of understanding of how plaster strength can affect the strength of a plastered straw bale, and also provided an insight on how the amount of water used in a mix can affect the strength of the plaster. The relative proportions of cement, sand and water were measured in (Kg) for different mix proportion and shown in the Table (3.5) below.

Table 3.5: Mix Proportion

Mix proportion	Cement content (kg)	Fine aggregate (kg)	Water content (kg)
1:3	360	1080	180
1:4	410	1575	205
1:6	327	1868	180

3.2 Water Absorption Test

As there were two distinct materials (straw bale & plaster) and perhaps they are vulnerable to water or moisture decomposition. Therefore, the need of water absorption test becomes more imperative to ascertain the percentage absorption rate of materials that bounded together as a straw bale block specimen. The measured water absorption of each specimen was calculated and tabulated in the Table (3.6) below.

Table 3.6: Water Absorption Test.

Mix Proportion (1)	Plaster Thickness (mm) (2)	Specimen Mark (3)	Weight of specimen before curing (kg). (M_F)		Weight of specimen after curing (kg). (M)		Wat. Absorpt. % $= \frac{M-M_F}{M_F} \times 100\%$(6)
1:3	10	A10	3.84	4.08	4.30	4.97	21.81
		A12	4.31		5.64		
	15	B20	4.60	5.03	5.60	6.12	21.67
		B22	5.45		6.64		
	20	C30	5.20	5.55	5.70	6.50	17.12
		C32	5.89		7.30		
1:4	10	A20	3.72	3.93	4.48	4.93	25.46
		A22	4.13		5.38		
	15	B30	4.76	4.96	5.26	5.75	15.93
		B32	5.16		6.24		
	20	C10	5.48	5.65	6.04	6.54	15.75
		C12	5.82		7.04		
1:6	10	A30	3.76	4.04	4.32	5.52	36.63
		A32	4.32		6.72		
	15	B10	4.62	4.79	5.34	5.82	21.50
		B12	4.96		6.30		
	20	C20	5.30	5.54	5.72	6.36	14.80
		C22	5.78		7.00		

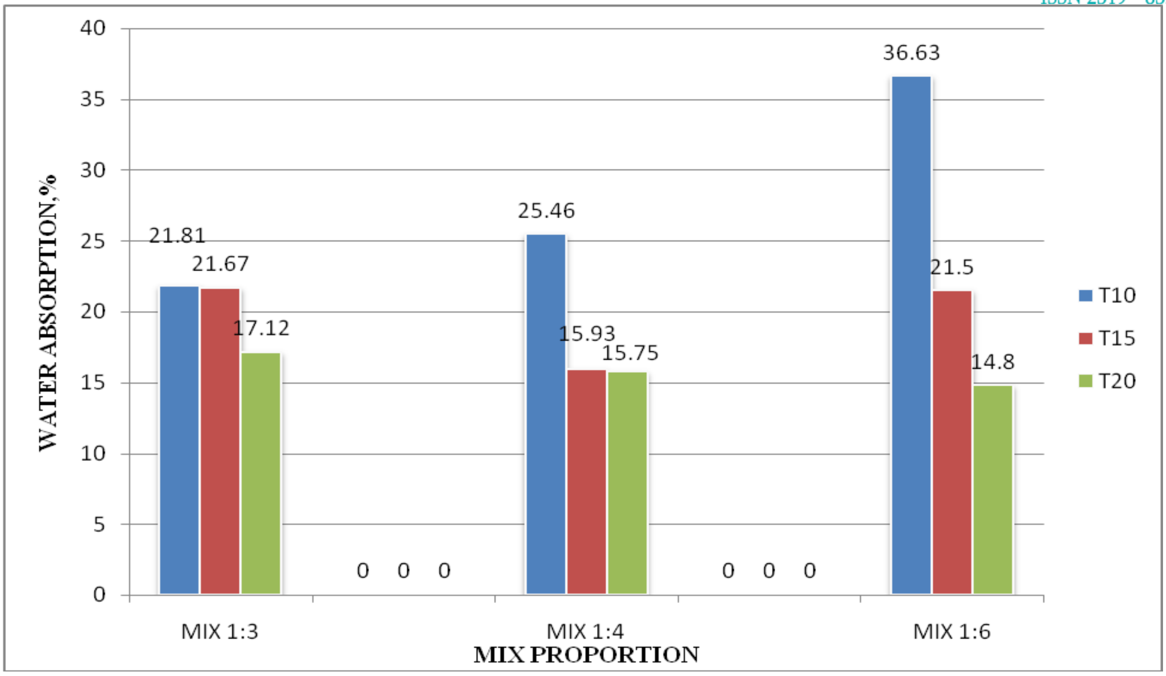

Figure 3.3: Water Absorption Rate of Plastered Straw Bale.

- From the Figure 3.3 above, the following can be observed;-

  It was observed that the mix with high cement content (mix 1:3) when compared with other mixes, exhibits significant low water absorption due to cement substrate content.

  It was observed that the smaller the thickness of plaster of the straw bale blocks, the more it absorbed water. Example, the maximum water absorption was found in 10mm plaster thickness of the weaker mix (1:6).
- It was observed that there was higher absorption rate in mix (1:3) for plaster 15, and 20mm than those in the mix (1:6) probably the fine aggregate might be affected by rain.

3.3 Compression Strength Test

The test was carried out on the eighteen plastered straw bale blocks for different mix proportion at 28-days curing. Each of the blocks with varying plaster thickness was loaded to failure and tabulated in Table (3.7) and their mode of failure points were noted for each of the block specimen.

From Figure 3.6shown before, the failure mode of the plastered bale tested was clearly failed as a result of the splitting cracks of plaster which is known as **global buckling**, that is typical well built wall behavior when eccentrically loaded.

Table 3.7: Compressive Strength of Plastered Straw Bale Blocks

Mix Proportion	Plaster Thickness (mm)	Specimen Mark	Load Failure (N)	Aver. Load Failure (N)	Compressive Stress (N/mm^2)	Aver. Compressive Stress (N/mm^2)
1:3	10	A10	42.60	51.55	1.895	2.292
		A12	60.50		2.689	
	15	B20	130.30	96.30	5.792	4.281
		B22	62.30		2.769	
	20	C30	154.00	136.05	6.843	6.046
		C32	118.10		5.248	
1:4	10	A20	62.30	45.10	2.769	2.001
		A22	27.90		1.241	
	15	B30	89.40	71.05	3.975	3.159
		B32	52.70		2.342	
	20	C10	126.90	120.45	5.642	5.354
		C12	114.00		5.066	
1:6	10	A30	48.00	38.25	2.130	1.698
		A32	28.50		1.265	
	15	B10	86.60	69.35	3.848	3.081
		B12	52.10		2.314	
	20	C20	125.00	116.30	5.555	5.168
		C22	107.60		4.781	

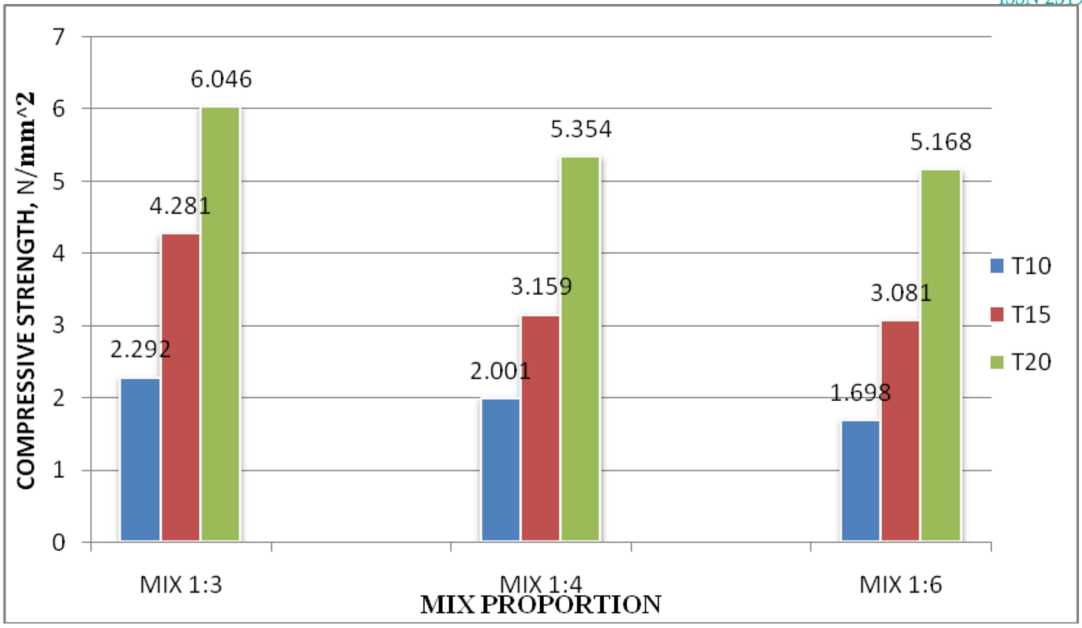

Figure 3.4: Compressive Strength versus Mix Proportion.

From Figure 3.4 above, it was noted out that the higher the thickness of the plaster, the higher the average compressive strength, and also, an increase in the plaster strength (mix 1:3) results in an increase of average compressive strength with maximum value (6.046 N/mm^2) obtained in 20mm plaster.

3.4 Discussion of the Test Results

The results of plastered straw bale blocks presented herein provide valuable perception into the structural behavior of the plastered straw bale when compared with our conventional building materials (Sand Crete blocks, bricks, masonry et cetera). A brief discussion was made in the following subsection.

3.4.1 Unit Dry Density of Plastered Straw Bale Blocks

The straw bales' densities as it presented in the Figure3.1 showing that, no standard density can be adopted because of the unused of baling machine but its variation in density, significantly predicted the effect of water absorption as well as compressive strength, example the group of A30 and A32 samples was found to have the least density as well as the compressive strength.

3.4.2 Water Absorption of Plastered Straw Bale Blocks

The water absorption behavior of the plastered straw bale can be seen from Figure3.3 that, the higher the cement content in the proportion and plaster thickness, the slower the water movement than that with the higher sand content in the proportion and least plaster thickness.

3.4.3 Compressive Strength of Plastered Straw Bale Blocks

It can be seen from Table3.7 that, the strength of the plastered straw bales was found to have a range of ultimate strengths between 1.698 and 6.046 N/mm^2, depending on the plaster strength, thickness, and water absorption rate. The results clearly shown that plastered straw bale have a structural ability (strength) than that stipulated by the British standard (BS 6073); the compressive strength of sandcrete of higher strength without cracking and shrinking should be the average of 10 blocks which range between 1.8 - 2.5 N/mm^2 (Adedeji, 2009).

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The results of experiments conducted on individual plastered straw bale has shown a satisfactory resistance against vertical loading, as shown by the results obtained the maximum compressive strength found as 6.046 N/mm^2 under category of 1:3 mix ratio with 20mm plaster thickness, while the minimum as 1.698 N/mm^2 under category of 1:6 ratio with 10mm plaster thickness which meets the requirement of standard compressive strength of sandcrete block (1.8 - 2.5 N/mm^2) stipulated by the British standard (BS 6073).

4.2 Recommendations

- It is recommended that, a plaster of 20mm to above thickness when applied to both side of the wall will give maximum requirement of a standard compressive strength of wall.
- For structural ability, and other properties like sound and thermal insulation, straw bale as a walling material is recommended.
- Awareness campaign should be made on the acceptability of straw bale techniques as a walling material.

V. ACKNOWLEDGMENT

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REFERENCES

[1] Adedeji A.A, (2007), "Introduction and design of straw bale masonry", Olad publishers Ent., Ilorin.

[2] Olayemi S.D, Adedeji A.A, (2011), "Effect of contact between straw bale wall composition and glass cement plaster", University of Ilorin, Ilorin.

[3] Emeka E, (2012, March 18), "Escalating cost of conventional construction materials in Nigeria", Punch newspaper, Retrieved from http:// www.punchng.com.

[4] Bruce King, (2003), "Load-bearing straw bale structures a summary of testing and experience to date", Ecological Building Network (EBNet), Retrieved from www.ecobuildnetwork.org/strawbale.

[5] Bruce King (2006), "Design of Straw Bale Buildings", Green Building Press San Rafael, CA.

[6] Downtown P, (2003), "Australia straw bales", Australia, Retrieved from www.ausbale.org.

[7] Vardy, S., MacDougall, C., (2006), "Compressive Testing and Analysis of Plastered Straw Bales", Journal of Green Building, 1(1), pp 63-79.

[8] California straw bale building code, 2001. HS18944, Australia, www.ausbale.org.

[9] Harvest Homes company, (2003), Canada, www.harvesthomes.ca.

[10] Carrick, J., and Glassford, J. (1998), "Preliminary Test Results Straw Bale Walls," The Building Officials Guide to Straw-bale Construction: Version 2.1, California Straw Building Association, California.

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