Design and Fabrication of a Compression Strength Testing Machine for Blocks and Clay Bricks

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Abstract

This study was carried out to design and fabricate a cost effective and efficient compression strength tester to carter for the needs of stakeholders in the blocks and bricks industries. In carrying out the project work a thorough study of the foreign testers and the requirements of the Nigerian industrial standards, NIS 87:2000 and NIS 74:1976 for blocks and clay bricks respectively was done. Design drawings and calculations were established and the machine was fabricated with well selected materials and components all sourced locally. The performance of the fabricated machine was finally evaluated against a standard foreign machine in the Standards Organisation of Nigeria using statistical methods and the result showed that the locally fabricated machine is 97% effective.

Keywords

Compression Strength, Machine, Blocks, Clay Bricks

Introduction

Compression testing is a method for assessing the ability of a material to withstand compressive loads. This test is commonly used as a simple measure of workability of material in service. Materials behave differently in compression than they do in tension so it may be important to perform mechanical tests which simulate the condition the material will experience in actual use. Compression testing is typically carried out on the following materials; Plastics, Foams, Rock, Concrete and Asphalt. It is rarely used to test metals (Bukar, 1992). Compressive strength of Blocks and Bricks is a critical parameter for determining the quality of these materials. The loads and forces acting on these materials while in service are compressive in nature and their ability to withstand such loads and forces without failure is a measure of their reliability. The compressive strength of most Blocks is below the minimum standard recommended by Nigerian Industrial Standard (NIS) 87: 2000 (Abdullah, 2005). The availability of a compression testing machine for Blocks and Clay Bricks is the first step to effective quality control and good manufacturing practice. The establishment of in-house quality control facilities by manufacturers for continuous assessment of product quality is a necessary requirement for ensuring compliance with relevant standard and maintaining product quality that will continue to meet the needs of the uninformed users. In Nigeria today, there is no effective locally fabricated compression testing equipment that is readily available and affordable for the local Blocks and Clay Bricks manufacturers. The foreign compression machines are expensive, rarely available and beyond the reach of the teeming local manufacturers. In line with the need to evolve a dual purpose effective compression machine with 100% locally sourced materials and components which will be cheap and readily available to both Sandcrete Blocks and Clay Brick manufacturers and will improve productivity, quality control, good manufacturing practice in the building material industry and also spur National economic growth, the design and fabrication of a compression strength testing machine is carried out.

Theoretical Analysis

Determination of Force required to be supplied by Hydraulic Jack

The hydraulic jack is expected to provide the force required for the compression of the specimen.

Let P = the maximum operating compressing pressure

A_c = surface area of block/brick sample to be compressed

The force required to be supplied by the hydraulic jack, F is given by the relation:

$$P = \frac{\text{Force}\ , F}{\text{Area}\ , A_c} \tag{1}$$

$$F = P \times A_c \tag{2}$$

Determination of Size of Supports

Let the force acting on each support be F_s

$$\text{Therefore, } F_s = \frac{F}{4} \tag{3}$$

Noting that the four supports are loaded in tension, then the diameter of each column is given by Gere and Timoshenko, (1999),

$$\sigma = \frac{nF_s}{A} \tag{4}$$

Where, σ = yield stress of material of support

n = factor of safety

A = cross sectional area of support

But the cross sectional area of each support is circular, hence,

$A = \frac{\pi d^2}{4}$, where d = diameter of support

Therefore,

$$\sigma = \frac{4nF_s}{\pi d^2} \tag{5}$$

Then,

$$d = \sqrt{\frac{4nF_s}{\pi\sigma}} \tag{6}$$

Determination of Thickness of Top Plate

The condition of the Plate is such that it is clamped at the four corners and the loading is taken to be uniformly distributed under the surface of the plate as the block/brick sample is compressed between it and the bottom plate. The thickness of the Top plate is given by Faupel and Fisher (1981),

$$\delta = \frac{0.0284wb^4}{Et^3}\left[\frac{1}{1.056(b/a)^5 + 1}\right] \tag{7}$$

Therefore,

$$t = \sqrt[3]{\frac{0.0284wb^4}{E\delta}\left[\frac{1}{1.056(b/a)^5 + 1}\right]} \tag{8}$$

where δ = maximum deflection

w = uniformly distributed load

b = breadth of plate

a = length of plate

t = thickness of plate

E = modulus of elasticity of material of plate

Determination of Thickness of Middle Plate

Unlike the top plate, the condition of the middle plate is such that it is not clamped at the four corners, it is free to move up or down the four cylindrical supports therefore, the reactions at the supports are horizontal and not vertical. The loading is taken to be uniformly distributed over the surface of the plate as the block/brick sample is compressed between it and the top plate. The thickness of the Middle Plate is given by Eugene A. and Theodore B. (1991),

$$\delta = k\frac{wb^4}{Et^3} \tag{9}$$

Therefore,

$$t = \sqrt[3]{\frac{kwb^4}{E\delta}} \tag{10}$$

where δ = maximum deflection

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w = uniformly distributed load

b = breadth of plate

t = thickness of plate

E = modulus of elasticity of material of plate

k = constant that depends on b/a

Determination of Thickness of Bottom Plate

The condition of the bottom Plate is such that it is clamped at the four corners and the loading is the concentrated type acting at the center of the plate. The thickness of the bottom plate is given by Eugene A. and Theodore B. (1991),

$$\delta = k\frac{Fb^2}{Et^3} \quad (11)$$

Therefore,

$$t = \sqrt[3]{\frac{kFb^2}{E\delta}} \quad (12)$$

where δ = maximum deflection

F = concentrated load

b = breadth of plate

t = thickness of plate

E = modulus of elasticity of material of plate

k = constant that depends on b/a

Determination of Weight of whole Assembly

The weight of the whole assembly is needed in order to determine the size of wheel axle. So the weight is given by the expression,

$$W = W_s + W_b + W_j + W_{sample} \quad (13)$$

where

W_S= weight of structure

W_b= total weight of bolts

W_j= weight of hydraulic jack

W_{sample}= weight of block/brick sample

Determination of Size of Wheel Axle

The wheels are acted upon by the weight of the entire assembly calculated in section 8. This is felt by the axles of the wheels. The size (diameter) of the each of the axles is determined thus:

Let d = diameter of each axle

A = Area of cross section of axle

$$d = \sqrt{\frac{4W}{n\pi\tau}} \qquad (14)$$

Description of the Machine

The compression machine consists of a load frame with suitable platens and a hand pump with pressure gauge as illustrated in figure 2.10. The pressure gauge is connected to the hand pump by means of a pressure pipe.

The gauge is calibrated and capable of measuring pressure up to 5000 psi or 34.45pa which though can not accommodate the test pressure of burnt clay bricks but that of sandcrete blocks. It can however test compressive strength of clay bricks but only for demonstrative purposes.

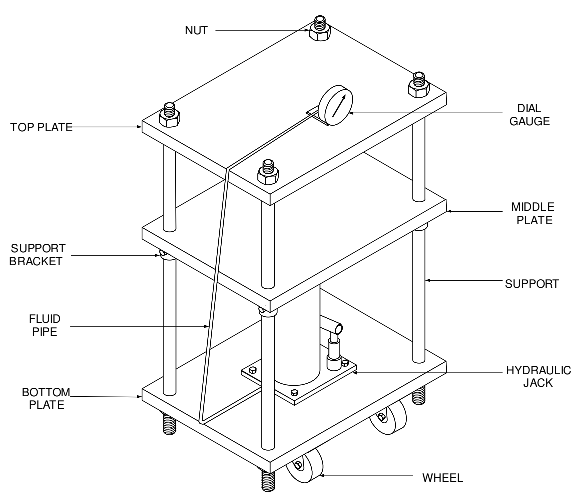

***Figure 1**. Fabricated compression testing machine*

Sample Selection

(i) The sandcrete blocks samples were selected as follows:

Five whole sandcrete blocks were selected at random from samples of 10 blocks separately for 450mm x 225mm x 225mm and 450mm x 225mm x 150mm in accordance to the NIS

87:2000. Accordingly the samples were drawn twice for testing on the Standard machine and fabricated machine.

(ii) The 10 samples each of the 450mm x 225mm x 150mm and 450mm x 225mm x 225mm were marked as:

x_{f16}, X_{f26}, X_{f36}, X_{f46}, X_{f56}, and X_{f66} for the 450mm x 225mm x 150mm sample tested on the fabricated machine, and X_{S16}, X_{S26}, X_{S36}, X_{S46}, X_{S56}, and X_{S66} for the 450mm x 225mm x 150mm sample tested on the Standard Machine; while x_{f19}, X_{f29}, X_{f39}, X_{f49}, X_{f59}, and X_{f69} for the 450mm x 225mm x 225mm tested on the fabricated machine, and X_{S19}, X_{S29}, X_{S39}, X_{S49}, X_{S59}, and X_{S69} for the 450mm x 225mm x 225mm sample tested on the Standard Machine.

Testing Procedure

Samples (wooden plates may be placed above and below the bed faces of the samples) to be tested were carefully placed between the centres of the plates of both the standard and fabricated compression testing machine.

Loads were then applied axially and uniformly without shock till failure occurred by means of a lever for the fabricated machine while for the Standard Machine the loading was electronically controlled.

Testing

(i) All the samples were tested dry on both the fabricated and standard machine

(ii) The maximum or failure loads of the blocks from each machine were recorded and tabulated in table 5A and 5B.

Table 5a. Measured Values of Compressive Strength of 450mm x 225mm x 225mm and 450mm x 225mm x 150mm sizes of Blocks obtained from the standard machine.

Block Work Size(Mm)	Son Compression Machine(Controls-Italy;2000kn Max Capacity)			
	Sample Code	Block Net Compression Area(Mm²)	Crushing Load(Kn)	Compressive Strenght
	Xs19	55925	22.37	0.40
	Xs29	„	22.93	0.41
	Xs39	„	28.52	0.51
	Xs49	„	29.08	0.52
	Xs59	„	23.49	0.42

Average				0.454
450x225x150	Xs16	34250	20.55	0.60
	Xs26	„	19.18	0.56
	Xs36	„	16.44	0.48
	Xs46	„	17.13	0.50
	Xs56	„	17.81	0.52
Average				0.532

Table 5b. Measured Values of Compressive Strength of 450mm x 225mm x 225mm and 450mm x 225mm x 150mm sizes of blocks obtained from the fabricated machine

Block size (mm)	Sample code	Block net compression area(mm²)	Crushing load		Compressive strength (N/mm²)
			PSI	Newtonn	
450x225x 225	Xf19	55925	1182	23489	0.42
	Xf29	,,	13312	27963	0.50
	Xf39	,,	10649	22370	0.40
	Xf49	,,	13844	29081	0.52
	Xf59	,,	10649	22370	0.40
Average					0.448
450x225x 150	Xf16	34250	8805	18495	0.54
	Xf26	,,	9783	20550	0.60
	Xf36	,,	8968	18838	0.55
	Xf46	,,	7826	16440	0.48
	Xf56	,,	8153	17125	0.50
Average					0.534

The Compressive Strength (N/mm^2) was calculated as

$$\frac{\text{Maximum load at failure}}{\text{Cross-sectional area of block}}$$

For the fabricated machine the compressive strength is obtained as given below;

0.4541b ≡ 1kg

0.0007 psi ≡ 1 kg/mm^2 ≡ 10 N/mm^2

Area of plunger = 3000.83 mm^2

Base

Force applied = Gauge reading x Area of plunger from the jack

= Gauge reading x 0.0007 x 10 x 3000.83 (N)

Compressive = Force from the jack (N/mm^2); (Bukar, 1992).

Strength of block Net Area of block

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Results

In order to present the results obtained to form the basis for comparison of the two machines, the compressive strength of all the samples measured were tabulated (See tables; 5C, 5D, 5E and 5F) and after all standard deviations calculated.

Table 5c. Calculated value of mean of compressive strength for size 450mm x 225mm x 225mm Block measured from the Standard Machine

No	Samples (X)	Size (mm)	Measured Values
1.	X_{S19}	450x 225 x 225	0.40
2.	X_{S29}		0.41
3.	X_{S39}		0.51
4.	X_{S49}		0.52
5.	X_{S59}		0.42
Av	$\overline{X}$		0.454

To calculate the standards deviation;

Let $S.D_{S9}$ denote Standards Deviation for the Standard Machine for 450mm x 225mm x 225mm samples

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$$S.D_{S9} = \sqrt{\frac{\sum_{i=1}^{N}(\overline{X}-X_i)^2}{N}}$$

$$= \sqrt{\frac{(0.40-0.454)^2+(0.41-0.454)^2+(0.51-0.454)^2+(0.51-0.54)^2+(0.52-0.454)^2+(0.42-0.454)^2}{5}}$$

$$= \frac{2.704x10^{-3}+1.764x10^{-3}+3.364x10^{-3}+4.624x10^{-3}+1.02x10^{-3}}{5}$$

$$= \frac{0.013476}{5} = 0.0519$$

Table 5d. Calculated value of mean of compressive strength for size 450mm x 225mm x 225mm block measured from the fabricated Machine

No	Samples (X)	Size(mm)	Measured Values
1.	X_{f19}	450 x 225 x 225	0.42
2.	X_{f29}		0.50
3.	X_{f39}		0.40
4.	X_{f49}		0.52
5.	X_{f59}		0.40
Average	$\overline{X}$		0.448

Let $S.D_{f9}$ denote Standards Deviation for the fabricated Machine,

$$S.D_{f9} = \sqrt{\frac{\sum_{i=1}^{N}(\overline{X}-X_i)^2}{N}}$$

$$= \sqrt{\frac{(0.42-0.448)^2+(0.50-0.448)^2+(0.4-0.448)^2+(0.51-0.54)^2+(0.52-0.448)^2+(0.40-0.448)^2}{5}}$$

$$= \sqrt{\frac{7.84x10^{-4}+2.704x10^{-3}+2x2.30410^{-3}+4.624x10^{-3}+5.184x10^{-3}}{5}}$$

$$= \sqrt{\frac{0.01328}{5}} = 0.0515$$

Table 5e. Calculated value of mean of compressive strength for size 450mm x 225mm x 150mm block measured from the standard Machine

No	Samples (X)	Size(mm)	Measured Values
1.	X_{S16}	450 x 225 x 150	0.60
2.	X_{S26}		0.56
3.	X_{S36}		0.48
4.	X_{S46}		0.50
5.	X_{S56}		0.52
Average	$\overline{X}$		0.532

Let $S.D_{S6}$ denotes standard deviation for standard machine for 450mm x 225mm x 150mm blocks

$$S.D_{S6} = \sqrt{\frac{\sum_{i=1}^{N}(\overline{X}-X_i)^2}{N}}$$

$$= \sqrt{\frac{(0.60-0.532)^2+(0.56-0.532)^2+(0.48-0.532)^2+(0.50-0.532)^2+(0.52-0.532)^2}{5}}$$

$$= \sqrt{\frac{4.624x10^{-4}+7.84x10^{-4}+2.704x10^{-3}+1.024x10^{-3}+1.44x10^{-4}}{5}}$$

$$= \sqrt{\frac{9.28x10^{-3}}{5}} = 0.043$$

Table 5f: Calculated value of mean of compressive strength for size 450mm x 225mm x 150mm block measured from the fabricated Machine

No	Samples (X)	Size(mm)	Measured Values
1.	X_{f16}	450 x 225 x 150	0.54
2.	X_{f26}		0.60
3.	X_{f36}		0.55
4.	X_{f46}		0.48
5.	X_{f56}		0.50
Average	$\overline{X}$		0.534

Let $S.D_{f6}$ denotes standard deviation for fabricated machine for 450mm x 225mm x 150mm blocks:

$$S.D_{f6} = \sqrt{\frac{\sum_{i=1}^{N}(\overline{X}-X_i)^2}{N}}$$

$$= \sqrt{\frac{(0.54-0.534)^2+(0.60-0.534)^2+(0.55-0.534)^2+(0.48-0.534)^2+(0.50-0.534)^2}{5}}$$

$$= \sqrt{\frac{3.6x10^{-5}+4.35x10^{-3}+2.56x10^{-4}+2.916x10^{-3}+1.156x10^{-3}}{5}}$$

$$= \sqrt{\frac{8.72x10^{-3}}{5}} = 0.041$$

Discussion of Results

The Standard Deviation values obtained from the fabricated machine for the 9 inches block, which was 0.0515 compared favourably with that for the standard machine which was 0.0519. Similarly the standard deviation for the 6 inches blocks for the fabricated machine was 0.041; this compares favourably well with that for the standard machine which was 0.043. It can therefore be inferred that the sensitivity of the two machines are almost the same.

Conclusion

The values of the standard deviation calculated from performance test carried out on five randomly selected block samples each of sizes; 450mm x 225mm x 225mm and 450mm x 225mm x 150mm, which were 0.051 and 0.041 respectively, from the locally fabricated compression strength testing machine for blocks and bricks compared favourably with those values obtained from the standard compression machine for blocks, which were 0.059 and 0.043 respectively, when the same test was done, under similar test conditions, on same sizes of samples of blocks randomly collected from the same source of mix and dimension as the former. That is, the deviation in accuracy of measurement of the locally fabricated compression strength tester from corresponding mean values obtained on the standard compression tester is less than 1%. Invariably, the locally fabricated compression strength tester for blocks and bricks can be applied to attest the quality of blocks manufactured in Nigeria, in accordance to the requirements of the Standards Organisation of Nigeria's standards (NIS 87:2000 for sand Crete blocks and NIS 74:1976 for burnt clay bricks), and will give values which would compare well with those from the standard (foreign) compression tester for blocks under the same test conditions

References

1. Abdullahi M. , The Compressive Strength of Sandcrete Block in Maitumbi Area of Niger State, Paper Delivered at 6th Annual Engineering Conference proceedings, FUT., Minna, PP 167-169, 2005.
2. Bukar, Y. A."Benefits of Enhanced Product Quality for Industries like Aluminum, Steel, Auto Mobile and related Industries" been paper presented at the seminar on Strategy for Developing Local Raw Materials for Metallurgical and Building Industries, 1992.
3. Eugene A. and Theodore B., *Marks'* Standard Handbook for Mechanical Engineers, 10th Edition, The McGraw-Hill Companies, Inc, 1999.
4. Faupel, J.H. and Fisher, F. E.,. Engineering Design. 2nd Edition, Wiley Interscience, Publishers, PP 216-217, 1981.
5. Gere, J. N and Timoshenko, S .P. Mechanics of materials. 4th SI Edition. Stanley Thornes Ltd, Cheltenham, PP 4, 1999.
6. NIS 87:. Nigerian Industrial Standard. Standard for Sandcrete Blocks; Published by Standards Organisation of Nigeria, 2000.
7. Nigerian Industrial Standard, NIS 74: Specification for Burnt Clay Building Units. Published by Standards Organisation of Nigeria, 1976.