

Termite Mound Clay as Material for Grain Silo Construction

By

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ABSTRACT

Silos are the most appropriate structures for the bulk storage of grains. Their performances are greatly influenced by the materials of construction and the climatic environment where they are used. Under the warm and humid climate prevalent in Nigeria, metal silos which are the predominant structures used for grain storage experience moisture condensation, resulting in grain deterioration. There is therefore the need to source for construction materials that will eliminate moisture condensation, durable, easy to construct, cheap and readily available to farmers. Termite mound clay was identified as a potential material. A 5.6m³ silo was designed and the prototype constructed with treated termite mound clay bricks. Temperatures were measured inside and outside the silo and the quality of grain stored in the silo was monitored over a period of two months. Viability tests of stored grain were also undertaken. Minimum and maximum temperatures outside the silo were 21°C and 36°C as against 20°C and 30°C inside the silo. Temperature fluctuation within the silo was 9.5 °C compared with 10.3 °C outside. Grain quality was maintained during the storage period, the viability before and after storage were 88% and 84% respectively. The treated termite mound clay silo demonstrated great potential for reducing temperature fluctuations and maintaining grain quality in storage. It is recommended that the simulation of moisture content, relative humidity and temperature profiles under full load should be undertaken. A comparative evaluation of the silo performance with those of other materials of silos construction should also be undertaken.

KEYWORDS : Termite, silo, temperature, fluctuations, viability, condensation

1. INTRODUCTION

Silos are common structures used for bulk grain storage because of their large unit capacities which could be as much as 500 tonnes. Although there are a number of construction materials such as steel, aluminum, concrete, wood, clay and rubber, the common commercial silos in use in Nigeria are constructed of steel or aluminum (Mijinyawa, 1999). Metal silos were first introduced to Nigeria in 1957 by the United States Department of Agriculture for the implementation of the co-operative grain storage programme of Western Nigeria taking advantage of the large storage capacities they offer. Steel and aluminum are easy to erect, make gas tight for fumigation and strong enough to withstand grain loads. In warm and

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humid climates, daily temperature fluctuation could be as much as 15°C for most part of the year. The use of metal silos with high thermal conductivities of as much as 250W/m^oK for aluminum and 62W/m^oK for steel (Parrish, 1973), results in moisture condensation on the inner walls and roof of the silo and its redistribution within the bulk grain. This situation results in the development of hot spots, grain dampness, mould growth, grain germination and rapid multiplication of insects in the event of infestation. Salty water in coastal areas corrodes the material besides the spoilage of the stored grains (Igbeka, 1983; Birewar, 1990; Talabi, 1996; Adesuyi, 1997). The twin problems of moisture condensation under a warm and humid environment such as in Nigeria and the prohibitive cost of the imported metal silos, limit their availability to a majority of farmers who may need to store their surpluses.

While some researchers have attempted to modify the metal silos to suit the local environment, others have advocated the use of local materials of construction. Advocates of local materials for grain silo construction opine that small sized silos could be produced to meet farmers' needs and at cheaper rates. With these, there will be savings in foreign reserve since the level of importation will reduce and local expertise in silo design and construction will be promoted.

Concrete plays a prominent role in silo construction both as wall and foundation. It is resistant to corrosion from inorganic acids. Single-walled mass concrete silos or those of blocks have been tested and found to reduce the severity of moisture condensation while those of double walls constructed from concrete staves and incorporating an air-space completely eliminated the problem of moisture condensation (Osobu, 1971; Lasisi, 1975). Concrete is however weak in tension and if used, must be reinforced with steel rods or welded mesh to withstand the lateral pressures due to the stored materials. Construction labour is high while it is also prone to rise in ground moisture and grains directly in contact with the floor may be damaged from moisture (Osunade, 1991). Laterized concrete silo made from a mixture of laterite soil, cement and gravel has also been developed (Osunade, 2000).

Rubber silos are most unsuitable for use under the warm humid climate as the material suffers severe moisture condensation under intense heat. It is prone to weathering from intense heat of the sun while it is also easily attacked by rodents. Little cracks soon graduate to large holes resulting in severe produce losses.

The low thermal conductivity of wood products of about 0.12 W/m °K (Parrish, 1973) and their availability most especially in Southwestern Nigeria encouraged their consideration for use in silo construction. Mijinyawa (1989), Alabandan (2002) and Alabandan (2006) investigated the potentials of wooden silos in reducing temperature fluctuations. They found that temperature fluctuations obtained within the wooden silos were lower than for those in metal silos. The susceptibility of wood to biodeterioration and difficulty of making the joints tight in order to eliminate crevices where insects could hibernate were some of its disadvantages. Termites build their tunnels from the soil into the wooden structures leaving the surface untouched which makes it difficult to detect an attack in the early stages (John *et al.*, 1995).

The use of clay in the construction of crop storage structures dates back to 1915, when a round barn or silo was constructed with hollow clay tiles at the Slatyon farm in Iowa, United States (Iowa FHPC, 2003). Different types of clay constructed structures are in present use in various parts of the world. These include the native rhumbu, the laterite – impregnated grass structure and the dried earth granaries in Northern Nigeria while the pusa bin is common in India. The major advantage of the native rhumbu is its ability to provide a cool environment for storage. This is attributed to the low thermal conductivity of about $1.15\text{W/m}^{\circ}\text{K}$ which is lower than that of concrete and metal silos (Osunade and Lasisi, 1998). Domestic grain storage especially those for use as seeds, is done in hermetic clay pots. The *kachia kothi* is a crop storage structure manufactured from clay and popularly used in Asia. Other types include the Mexican store which is a closed clay silo in curved walls that is difficult for rats to gain access.

1.1 Definition and Properties of Clay

Although a number of authors such as Cooper (1991) and Morris (1997) have given different definitions, clay can be defined as a very fine-grained soil of less than 0.1mm in size and which is plastic when moist but hard when fired. The plastic nature under wet condition enables clay to be moulded into any shape which is retained upon drying. Good clay should therefore exhibit this plastic property. The suitability of any clay for moulding can be tested through moulding about 200mm coil (about the size of a finger) on a slab. If the coil cracks in the outer edges, the clay is probably less plastic. If on the other hand, the coil does not crack in the outer edges, the clay has adequate plasticity and is a good material for moulding (Daniel, 1977). When used in construction, clay often undergoes some treatments which improve the properties. When used as bricks, clay is subjected to a temperature of as much as 500°C or even higher. During this process, the alumina content in the clay melts thus raising the burning temperature to about 275°C which is much higher than temperatures experienced in fire accidents. This is why clay products possess excellent fire resistant properties compared to wood (Hall and Jackman, 1975; Lucas and Fuwape, 1984; Schaffer, 1988; Schaffer, 1992; FPL, 1974; Hendry *et al*, 1987). Parker (1998) reported that besides the improvement in fire resistance, the elevated temperatures also improve the resistance to moisture penetration.

The pile of earth made by termites resembling a small hill is called a termite mound. It is made of clay whose plasticity has further been improved by the secretion from the termite while being used in building the mound. It is therefore a better material than the ordinary clay in terms of utilization for moulding (Odumodu, 1991). This type of clay has been reported to perform better than ordinary clay in dam construction (Yohanna *et al*, 2003). The clay from termite mound is capable of maintaining a permanent shape after moulding. Termite mound clay is being considered for use in silo construction because of its plasticity and less prone to crack when compared with ordinary clay. Heat treated termite mound clay units are resistant to wear, abrasion and penetration by liquids (Parker, 1998). Termite mound clay has low thermal conductivity and expectedly should reduce solar heat flow into the silo enclosure and regulate temperature fluctuations within the storage environment.

The objective of the work reported in this paper was to develop a durable, efficient, affordable and cost effective silo that could be sited on locations close to the small scale farmers to store their grains.

2. MATERIALS AND METHODS

The materials and methods were divided into three parts: design, construction and testing of the silo prototype.

2.1.0 Design

2.1.1 Design Considerations

In the design of the silo, a number of factors aimed at ensuring effective utilization, ease of construction and management, considering the level of technology available in the rural communities and accessibility to the intended beneficiaries were taken into account. Information obtained from the extension unit of the Ondo State Agricultural Development Project (Ondo State ADP, 2005), puts the annual grain production per farmer at 4 tonnes and this value was used as the capacity for the silo. It is noted that some farmers may not produce up to this capacity while those who produce as much may not store all the harvests but the choice of this capacity is to make provision for future expansion. Maize is the most common grain cultivated in the area where this study was undertaken and its properties were used in the design.

2.1.2 Silo Shape and Dimensions:

In order to minimize areas of stress concentrations, a cylindrical shape was chosen and for the estimated capacity of 4 tonnes using shelled corn of a density 720kg/m^3 and angle of repose of 27° , an internal diameter of 2.0 m and height of 1.8 m were considered adequate for the silo.

2.1.3 Pressure Analysis

The ratio of the depth – to - diameter shows that the silo is a shallow type. The basic difference between a deep and a shallow silo is the presence of wall friction in a deep silo and its absence in a shallow one. Gurfinkel (1979) reported that even in the deep silos where the wall friction initially exists, it disappears after sometime as a result of the deposition of wax-like materials on the wall surface from the grains and the wall becomes smooth taking the form of a shallow silo. The silo was therefore designed as a shallow one using the Rankine approach reported by Gaylord and Gaylord (1984). The design therefore assumed only the presence of lateral and floor pressures due to the stored grains. These were calculated from the following equations

$$L = wy \left(\frac{1 - \sin \theta}{1 + \sin \theta} \right) = wy \tan^2 \left(45 - \frac{\theta}{2} \right) \dots\dots\dots \text{Equation 1}$$

$$F_v = w.h \quad \dots\dots\dots \text{Equation 2}$$

where

L = lateral pressure per unit of wall area , N/m²

w = unit weight of the stored material, N/m³

y = distance from the top surface of grain to the point within the grain at which the pressure is considered, m

θ = angle of repose of the stored material, degrees

h = height of grain above the floor, m

F_v = floor pressure due to grains, N/m²

The maximum lateral pressure was calculated to be 5.8kN/m² while the floor pressure was 12.7kN/m². A factor of safety of 1.4 was used to take into account dynamic loads that may be developed during unloading. The design loads were obtained as 8.1kN/m² for the lateral pressure and 17.8kN/m² for the floor.

2.1.4 Silo Wall Thickness

A number of empirical formulae are available for the estimation of wall thickness of small capacity silos constructed from clay. Some of these are the FAO (1987) method given by

$$t = \frac{R.P_h}{T_s} \quad \dots\dots\dots \text{Equation 3}$$

where t, is the wall thickness in m, R is the internal radius of the silo in m, P_h is the maximum lateral pressure in N/m² due to the stored grains and T_s is the maximum tensile strength in kN/m² of the wall material. For dry clay soil, T_s is 30 – 60 kN/m². (FAO, 1987)

The Ghali (1979) method is given by the following equation

$$t = \frac{h}{15} \quad \dots\dots\dots \text{Equation 4}$$

where t is the wall thickness in meters, and h is the wall height in meters

Bengtsson and Whitaker (1986) gave the following equation

$$t = D + 12 \quad \dots\dots\dots \text{Equation 5}$$

where t is the wall thickness in centimeters and D is the silo diameter in meters.

The silo wall thickness was calculated using each of the three approaches. The values obtained were 13.5 cm, 12 cm and 14 cm for the FAO (1987), Ghali (1979) and Bengtsson and Whitaker (1986) methods respectively. A wall thickness of 15 cm was selected. This dimension will be adequate to take care of any shrinkage on drying.

2.1.5 Number of Bricks Required

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In estimating the number of clay bricks that would be required for the silo wall, the circumference and height of the wall, brick dimensions and thickness of the binding mortar were taken into account. Openings on the wall such as the unloading chute were ignored. The following formula was used

$$N = \frac{2\pi RH}{(L_b + m_t)(h_b + m_t)} \dots\dots\dots \text{Equation 6}$$

where R is the external radius of the silo, m

H is the height of the silo, m

L_b and h_b are the length and height of the bricks, m

m_t is mortar thickness, m.

The dimensions of the bricks were 0.215 x 0.150 x 0.065 m and a mortar thickness of 0.012 m was assumed. The number of bricks was calculated as follows

$$N = \frac{2(3.142)(1.15)(1.8)}{(0.215 + 0.012)(0.065 + 0.012)} = 745$$

In order to cater for breakages during construction and preparation of the mix to be used as mortar, 900 units were recommended.

2.1.6 Design against Wind Load

Besides grains, wind is another factor that imposes loads on a silo and which must be considered. A number of empirical formulae are available for predicting this but the modified formula of Barre and Sammet (1966) given as follows was used

$$P = 0.05C A V^2 \dots\dots\dots \text{Equation 7}$$

where

P = the load due to wind imposed on the silo, N

C = pressure coefficient which takes into account the orientation of the structure to main wind direction and is usually taken as 0.8 for cylindrical silos

A = projected area of the structure, m^2

V = wind velocity in the environment, km/hr

Using a wind speed of 112 km/hr for the silo location (NCP, 1973) and a projected area of $4 m^2$, the overturning moment was calculated as 1.98 kN-m. The resisting moment due to the self weight of the silo was calculated as 237 kN-m which far exceeded the overturning moment. This shows that even if the silo was only placed on the ground without any anchorage, there would be no overturning. In practice, the silo will not only be anchored but the stored materials will increase the value of the resisting moment. The silo is therefore of adequate stability against wind load.

2.2.0 Construction

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The silo construction comprised of the collection of clay and brick making, and the construction of the foundation, the wall, the roof and the accessories.

2.2.1 Clay Collection and Brick Making

In order to be able to obtain clay from the mounds, the termites were evacuated through the application of chemical powder (pestox) into the broken mounds and the surroundings. The lumps of termite mound clay were then collected and deposited at a clean site. Size reduction of the clay lumps was achieved through pounding with pestle. The clay was then mixed with water in the ratio of two volumes of termite mound to one volume of water. The wet clay was then poured into a 215 x 150 x 65 mm wooden mould placed in a manually operated moulding machine and vibrated to ensure compaction and appropriate shape forming. The bricks were then removed and left for five days to dry naturally. They were thereafter burned in a mud-kiln with the use of firewood as the source of heat (Figure1). The kiln temperature was about 500°C monitored with a thermocouple.



Figure 1: Dried termite mound bricks being set for burning in a mud-kiln



Figure 2: Veneers and iron rods used to mark the circular foundation

2.2.2 Construction of the Foundation

In order to define the perimeter of the silo foundation, the two ends of a 1300 mm long binding wire were tied to 30 cm long iron rods. One of the rods was placed at the proposed centre of the silo while the other was used to draw a circle defining the outer radius of the silo. The foundation was excavated and the footing cast. Strips of 30 cm height were obtained from 3 mm thick veneer and bent to form the inner and outer circumferences of the foundation and supported at intervals with iron rod pegs (Figure 2). Stones were then used to construct the foundation. The foundation was filled with laterite after which a concrete floor of 1:3:5 mix and 40 mm thickness was constructed. The floor was slopped at 8° towards the discharge chute in order to aid grain discharge . Figure 3.



Figure 3 Round concrete floor on stone foundation



Figure 4: Setting of bricks in progress

2.2.3 Setting and Laying of Bricks on the Wall

Because of the concrete floor cast over the foundation, it was necessary to redefine the silo circumference so that the wall could be correctly positioned. This was re-established using the binding wire and rods. The bricks were then set in layers using slip clay and grog as the mortar. This was progressively done till the required height was reached, (Figure 4). Allowances were made for the locations of the manhole and the discharge chute.

2.2.4 The Roof

The shape of the roof was conical with the circular base resting on the silo top. The wall plate made of 75mm x 100mm timber was secured onto the wall top using metal bands. Roof joists of 50mm x 100mm were securely nailed on the wall plate and across the circular surface with 75mm long wire nails. The roof was extended below the top of the wall to provide 300 mm overhang. The truss was covered with corrugated iron sheets and asbestos-cement sheets used as ceiling Figure 5.



Figure 5: Completed roof truss of the silo



Figure 6: Loading chute attached to the roof truss

2.2.5 Accessories

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The silo accessories were the loading and discharge chutes, and the manhole for inspection. The loading chute comprised of a trapezoidal wooden frame of 400 mm x 300 mm and height of 300 mm and attached to the roof truss (Figure 6). The chute was covered with a removable roofing sheet with the hinge points provided with rubber gaskets to eliminate moisture entry into the silo. The manhole provided entry into the silo to carry out any necessary repairs and cleaning. This was located on the wall towards the base and measured 560 mm x 480 mm. The discharge chute of dimensions 160 mm x 150 mm formed part of the manhole. Loading was accomplished with the use of a ladder which was only in place when loading was to be done. The completed silo is shown in Figure 7.



Figure 7: Completed silo showing the manhole to which the discharge chute is attached

2.2.6 Precautionary Measures

In order to protect the silo structure and the contents, a number of precautionary measures were taken into account in its design and construction. Some of these precautions included the followings

- i) An eave of about 30 cm was provided to prevent the entry of rainwater into the silo and to move away the drop line from the base of the silo so that splashing rain did not erode the foundation and wall. The roof pitch of 34.9° ensured adequate roof drainage and prevented ponding. The concrete floor supported on a stone base foundation prevented flooding and moisture capillary action. The silo site had adequate drainage.
- ii) Both sides of the silo wall were smooth which prevented insect hibernation inside and made it difficult for rodents to climb outside. The eave was sealed making it impossible for rodents, birds lizards and insects to gain access to the silo. The walls and floor were thick and strong enough to resist burrowing by rodents. The surroundings of the silo were well cleaned of vegetation and debris that could either harbour rodents or attract insects.

2.3.0 Testing

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Three tests were carried out in order to establish the efficacy of the silo. These were temperatures measurements, grain quality monitoring and viability test of stored grains.

2.3.1 Temperature Monitoring

One of the arguments in favour of using the termite mound clay for the silo construction is that in view of its low thermal conductivity, it should be able to reduce temperature fluctuations within the silo. This was why the measurement of temperature fluctuations inside and outside the silo was carried out. The temperature fluctuations inside the silo and the environment where it was located over a period of 24hrs were measured by placing combined maximum and minimum thermometers inside and outside the silo for a period of 60 days. Temperatures readings were taken three times daily at 06:00 h, 12:00 h and 18:00 h.

2.3.2 Grain Quality Monitoring

One tonne of maize was purchased from the open market in Ondo , cleaned and dried, and samples were taken for test. The samples were manually sorted into foreign matters, moulded grains, broken grain and infested grain. The percentage of each of the groups present in the sample was calculated as follows

$$P = \frac{100W_i}{W_t} \dots\dots\dots\text{Equation 8}$$

where

P = % of sample that belongs to the particular group.

Wi = Weight of the sample that belongs to the particular group.

Wt = Total weight of the sample

The moisture content of the maize was determined using a digital moisture meter. The results were compared with the specification set by the Strategic Grains Reserve Scheme for grains meant for storage in silos (Table 1) to ensure minimum standard before storage. The grain was then loaded into the silo and left for a period of sixty days. At the end of the test period, the grain was unloaded and the same analyses were carried out.

Table 1: Specification for Grains to be Stored in a Silo

Parameter	Maximum value
Moisture content (%)	12.0
Test weight/hectoliter weight	68 – 75Kg/hl
Broken grains (sorghum, soyabean, cowpea and maize)	1 %
Damaged grain due to insects	1%
Damaged grain due to mould	1%
Foreign matter	1%
Grain age	1 year

Source: National Strategic Grain Reserve Scheme, Akure Station, (2005)

2.3.3 Viability Test

Stored grains are often required for use as seeds and it was considered necessary that viability should be one of the indices of measuring the efficacy of the silo. Pre - and post-storage viability tests were therefore carried out using the method suggested by Ellis (1988). The result was calculated from the formula

$$V = \frac{100N_g}{N_t} \dots\dots\dots\text{Equation 9}$$

V = viability in %

N_g = Number of seeds that germinated

N_t = Total number of seeds planted

3. RESULTS AND DISCUSSION

3.1 Temperatures Pattern

The minimum ambient temperature recorded in the morning was 21°C while the highest values were recorded at noon, reaching up to 36°C and expectedly reduced in the evenings. In many cases, the temperatures remained at 35°C in the evenings. Temperature readings within the silo were nearly constant at 20°C in the mornings and 30°C in the afternoons. Temperature fluctuation within the silo was slightly more stable than outside with mean daily fluctuations of 9.5°C and 10.3°C respectively. These values are significant because a lower average temperature fluctuation within the silo compared with a higher ambient average is an indication that the silo enclosure would store grain at a lower temperature.

3.2 Grain Quality before and after Storage

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The results of the grain quality assessment before and after 60-day storage are presented in Table 2. The initial moisture content of the maize was 12% and after unloading the grains, this value remained unchanged. This value was recorded despite the occurrence of rainfall for some days within the storage period. The constant value of the moisture content of maize before and after storage was a confirmation that the maize neither gained nor lost moisture while in storage. The grain was not wet and this showed that there were no leakages from the roof and wall of the silo when it rained. The maize seeds had no insect holes on them and there were no changes in their texture since none of them was powdery. These observations confirmed that the maize seeds were not subjected to insect infestation while in storage. The maize shape remained intact as there were no noticeable changes in the common oblong maize shape. There was no evidence of rodents attack on the stored maize. Contamination from rodent's faeces was also absent.

3.3 Maize Viability before and after Storage

The pre-storage viability was 88% which fell to 84% after storage. This level is well above 60% which is the minimum recommended for seeds to be used for planting (Ellis,1988). The silo is therefore a good store for seeds.

Table 2: Quality of Maize before and after Storage

Parameter	Quality of Maize before Storage	Quality of Maize after Storage
Foreign material (%)	0.10	0.10
Mouldy grain (%)	0.26	0.28
Broken grain (%)	0.09	0.10
Insect infested(%)	0.03	0.03
Moisture content (%)	12 (dry basis)	12 (dry basis)
Seeds viability (%)	88	84

3.4 Benefits of the Silo

- a) At present, there is very little use of the termite mounds which are in abundance in many parts of Nigeria and especially in the study area. There is assurance of raw material and silos can readily be made available to farmers.
- b) The design is simple and the construction can be readily accomplished locally.
- c) While the high unit capacity of silos especially the metal ones was the main attraction for their use at inception for cooperative grain storage programmes, the collapse of the cooperatives has rendered most of the commercial silos including those of the Strategic Grain Reserve Scheme redundant for lack of grains to store. Small capacity silos such as the one developed in this study will suit the requirement of the individual farmers and the frequency of use will be high.

4. CONCLUSIONS AND RECOMMENDATIONS

A grain silo has been designed, fabricated from treated termite mound clay and tested. The silo demonstrates some prospects for use in grain storage limiting some of the problems experienced with other materials especially temperature fluctuations and moisture condensation. The availability of the material of construction and relatively simple construction and management techniques will make the silo cheap and within the reach of the small scale farmers. Further work should focus on temperature, relative humidity and moisture content monitoring under full load for longer storage period. A comparative evaluation of the silo performance with those of other materials of silos construction should also be undertaken.

5. REFERENCES

- Adegunloye, F.O. (2007). Utilisation and Evaluation of Treated Termite Mound Clay Bricks for Grain Silo Construction., *Unpublished PhD thesis* . University of Ibadan, Nigeria.
- Adesuyi, S. A. (1997). Preservation of Grains in the Tropics with Special Reference to Nigeria. *Applied Tropical Agriculture (2)*, 50 –56. Federal University of Technology, Akure, Nigeria.
- Alabadan, B. A. (2002). Modelling the Performance of a Hexagonal Wooden Silo During Storage of Maize (*Zea mays*) *Unpublished PhD thesis*, University of Ibadan, Nigeria,
- Alabadan. B.A.(2006). “Evaluation of Wooden Silo during Storage of Maize (*Zea mays*) in Humid Tropical Climate”. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript BC 05 013. Vol. VIII. February, 2006.
- Barre, H. J. and L.L. Sammet (1966) *Farm Structures*. John Wiley & Sons, New York
- Bengtsson, L. and J. H. Whitaker (1986). *Farm Structures in Tropical Climates*. A Textbook for Structural Engineering and Design FAO, Rome.
- Birewar, B. R. (1990). Development of Improved On-farm Grain Drying Facility in Nigeria. *AMA*, 27(1) 51-53.
- Cooper, E. (1991). *A Handbook of Pottery*. Longman Publishers, Great Britain.
- Daniel, R. (1977). *Clay and Glazes for the Potter*. Pitman Publishing, London.
- Ellis, R.H. (1988). The Viability Equation, Seed Viability Nomographs, and Practical Advice on Seed Storage. *Seed Science & Technology*. 16: 29-50
- FAO (1987). Construction and Operation of Small Solid-Wall Bins. Food and Agricultural Organization of the United Nations. *Agricultural Services Bulletin* No 69 (Eds) Ole Bodholt and Aliou Diop.
- FPL (1974). Wood Handbook: Wood as an engineering material. Forest Products Laboratory, U.S. Department of Agriculture Handbook No 72
- Gaylord, E. H. and C. N. Gaylord (1984). *Design of Steel Bins for Storage of Bulk Solids*. Prentice-Hall International Series in Civil Engineering and Engineering Mechanics. Prentice-Hall, Inc, New Jersey.
- Ghali, A. (1979). *Circular Storage Tanks and Silos*. E & F.N. Spon Ltd 11, New Fetter Lane, London.

- Gurfinkel, G. (1979). *Reinforced Concrete Bunkers and Silos in Structural Handbook*. In (Eds) E.H. Gaylord and C. N. Gaylord. McGraw – Hill Book Company, New York. 2nd Edition.
- Hall, G.S. and Jackman, P.E. (1975). Performance of Timber in Fire. *Timber Trades Journal* (Nov.15): 38 – 40.
- Hendry, A. W; Sinha, B. P and S. R. Davies, (1987). *Load Bearing Brickwork Design*. 2nd Edition. Ellis Horwood Series in Engineering Science. Ellis Horwood Ltd. England.
- Igbeka, J.C. (1983). Evaluation of Grain Storage Techniques in Nigeria. *African Journal of Science and Technology*. (AJST) ANSTI-UNESCO, Nairobi 2: 22 – 34.
- IOWA. Iowa Falls Historic Preservation Commission (2003). The Slayton Farm Round Barn. *National Register of Historic Places Hardin County, Iowa*.
- John V.W; Wolfram, P.and H. Fritz (1995). *Rural Building Course*. IT Publication Ltd. London.(1) .143 – 144.
- Lasisi, F., (1975). A Tropical Small Farm Storage Structure for Grains. *The Nigerian Agricultural Journal*. 12 (1): 9 – 22
- Lucas, E.B and Fuwape, J.A. (1984). Burning and Related Characteristics of Forty-two Nigerian Fuelwood Tree Species. *The Nigerian Journal of Forestry*. 14 (1 & 2): 45 - 52
- Mijinyawa, Y (1989). The Use of Wood Products in the Design and Construction of a Grain Silo for the Humid Tropics. *Unpublished PhD thesis* . University of Ibadan, Nigeria
- Mijinyawa, Y. (1999). Wood Products for Grain Silo Construction. *Journal of Engineering Applications* 1(2): 25 – 29
- Morris, C (1997). *Academic Press Dictionary of Science and Technology*. Academic Press, Harcourt Brace Jovanovich Publishers, New York.
- National Strategic Grain Reserve Scheme, Akure Station, (2005). Specification for grains to be stored in a silo. *Unpublished Laboratory Manual*,
- Nigerian Standard Code of Practice. *NCP 1: 1973 Part 3: Loading*. Federal Ministry of Industries, Lagos.
- Odumodu, R. C. (1991). Clay Block Industry in Nigeria, Problem and Prospects. *Engineering Focus* 3(6) 37 – 40. NSE Publication, National Engineering Centre, Victoria Island, Lagos.
- Ondo State Agricultural Development Project (2005): *Unpublished File Records on Annual Production of various crops*. Ministry of Agriculture, Akure, Nigeria
- Osobu, A. (1971). Structural efficiency and Economics of Locally Produced and Imported structures. *A paper presented at the Regional Agricultural Research Seminar* co-sponsored by the Ford Foundation, IITA and IAR&T, Moor Plantation Ibadan.Held at the University of Ibadan July 26 – 30, 1971. 4 pages.
- Osunade, J.A and Fola Lasisi (1988). Use of Laterized Concrete Silos for On-the- farm Grain Storage. *Proceedings of the 1988 International Conference of the Nigerian Society of Engineers*, pp 64 – 69.
- Osunade, J. A. (1991). Design of Storage Systems I. *Technical Paper Presented at a Workshop on Design, Construction and Maintenance of Food Storage System* Organized by the Nigerian Society of Engineers, Victoria Island, Lagos, Nigeria. 1 – 3 May
- Osunade, J.A (2000). Nutritional Quality of Maize Grains Stored in Laterized Concrete Silo. *Journal of Agricultural Engineering and Technology*, (2000):8, 59 – 64
- Parker, P. S. (1998). *Structural Design*. McGraw Hill Concise Encyclopedia of Science and Technology 4th Edition, New York.

- Parrish, A. (1973). *Mechanical Engineers Reference Book*. 11th Edition. Butterworth and Company Publishers, London. 2-25
- Schaffer, E. (1988). How Well Do Wood Trusses Really Perform During Fire?. *Fire Journal* 82(2): 57 – 63.
- Schaffer, E. (1992). Fire Resistive Structural Design. *In Proceedings, International Seminar on Wood Engineering, University of Denver, Colorado, U.S.A.* Pp. 47 – 60.
- Talabi A. E. (1996). Implementation of National Food Security Programme: Experience So Far. *In Proceedings of the National Workshop on Strategic Grains Reserve Storage Programme*. Federal Ministry of Agriculture, Abuja. 26th – 28th July. 1996
- Yohanna, J.K; A. U. Fulani; E.D. Azagaku and A. D. Anda (2003). Prospects of Using Ant Hill Materials for the Control of Seepage in Earth Dams. *Proceedings of the Nigerian Institution of Agricultural Engineers* (25),135 – 143