AFFORDABLE, RELIABLE AND SUSTAINABLE BUILDINGS: INNOVATIVE CONSTRUCTION MATERIALS AS PANACEA

INAUGURAL LECTURE SERIES 54

BY

AKEEM AYINDE RAHEEM

B.Sc, M.Sc., Ph.D. MNIOB, CORBON Regd. Bldr.

Professor of Building

Delivered on

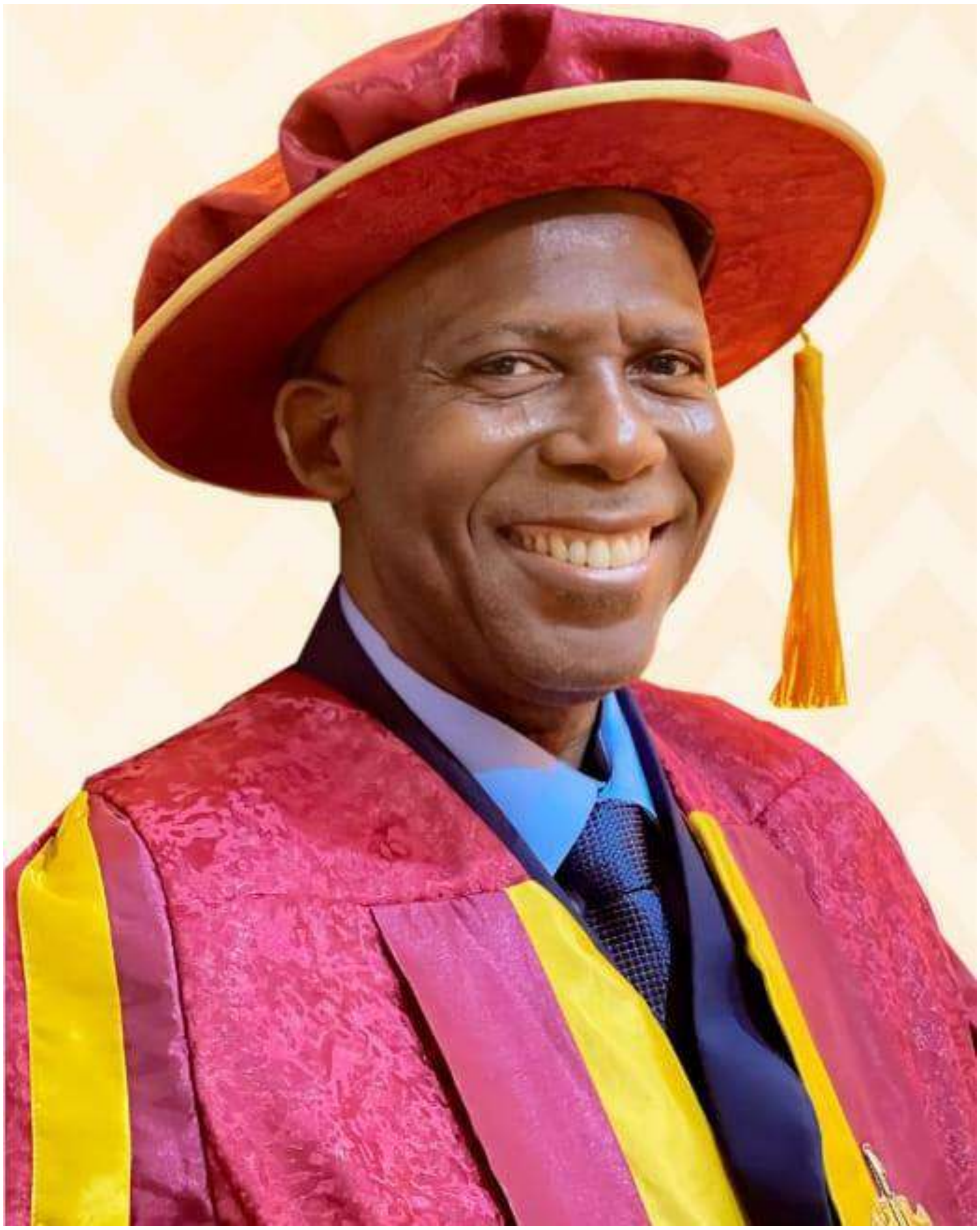
THURSDAY 1ST JUNE, 2023

At

The Great Hall,

Ladoke Akintola University of Technology,

Ogbomoso, Oyo state, Nigeria



CITATION OF PROF. AKEEM AYINDE RAHEEM

The blooming of trees heralds the season of plenty. This is the metaphor for the birth of the astute academic, profound researcher, thorough-bread professional, great mentor, and respected community leader here standing before this great assembly of intellectuals. He is Professor Akeem Ayinde Raheem who was born on June 3, 1963, in the city of Lagos. His educational adventure started in Lagos in Progressive Primary School Surulere, as a pupil. He obtained B.Sc. (Honours) in Building from the University of Ife (Now Obafemi Awolowo University), Ile Ife in 1987 before proceeding to the University of Lagos, Akoka where he obtained M.Sc. (Construction Technology) in 1996 and then Ph.D. (Building Structures) in 2006 from Obafemi Awolowo University, Ile Ife.

He started his career as a Graduate Assistant in the Department of Civil Engineering, LAUTECH, Ogbomoso in 1992 and rose through the ranks and files of academic cadre to becoming a Professor of Building in the Department of Civil Engineering on October 1, 2013. His wealth of experience was built from various positions and capacities that he had served within and outside the university campus. Principally, he has served as the Ag. Head, Civil Engineering Department; Departmental Examination Officer, Departmental Postgraduate Programmes Coordinator, Deputy Dean, Faculty of Engineering and Technology; Chairman, Faculty Adhoc Building Committee, Chairman, Industrial Training and Placement Committee, Chairman, Local Organising Committee of the 2nd and 3rd International Conference on Engineering and Technology Research, Faculty of Engineering and Technology; Chairman, Faculty Time Table and Examination Committee, Chairman, Faculty Postgraduate Advisory Committee, Chairman, Faculty Induction Committee, Chairman, Faculty Lecture Series Committee; Chairman, Examination Invigilation Monitoring Team, Faculty of Engineering and Technology; Member, University Curriculum Committee; Member, Board of Postgraduate School; Chairman, Scholarship and Prizes Committee; and Chairman, Parents and Teachers Association, LAUTECH Staff School; to mention a few.

As an active researcher and project leader, he has led some funded research and has more than eighty (80) articles in reputable journals to his credit. He has successfully supervised Six (6) Ph.D. theses, fourteen (14) M. Tech. dissertations and over 500 B. Tech. Students' projects while many are on-going. He has served as an external examiner to the Civil Engineering Department, Osun State Polytechnic, Iree; Building Department, Obafemi Awolowo University, Ile-Ife; Building Department, Federal University of Technology, Minna; Civil Engineering Department, University of Ibadan, Ibadan; Civil and Environmental Engineering Department, Kwara State University, Malete, Ilorin; Civil Engineering Science Department, University of Johannesburg, South Africa; Civil and Environmental Engineering Department, The University of the West Indies, Jamaica; Civil Engineering Department, University of Abuja, Abuja and Building Department, University of Lagos, Akoka. He has served as Professorial Assessor to many Universities within and outside Nigeria. He has also taught at various levels as a Visiting Professor at the University of Lagos, Akoka; Building and Quantity Surveying Department, College of Environmental Sciences and Management, Caleb University, Lagos and Department of Civil and Chemical Engineering, University of South Africa, Johannesburg, South Africa. He has attended and presented papers at both local and international professional conferences. He has served as a reviewer to several national and international scientific and trade journals.

Prof. Raheem is a member of pertinent professional bodies and networks. He is a graduate member, Nigerian Society of Engineers; Corporate Member, Nigerian Institute of Building, and a Fully Registered Builder with CORBON. He is a member, Technical Committee on the proposed Muslim Hospital for Ogbomoso as well as member and later chairman, National University Commission (NUC) Accreditation Teams. In his quest to serve a larger community, he was a Facilitator, National Population Commission; WAEC Examiner in Building Construction; Member, Board of Trustee Igbo-Agboin Muslim Community; Treasurer, Challenge Landlords Association, Challenge area, Iwagba, Ogbomoso, Member, Board of Trustee Muslim Scholarship Fund Nigeria, and Secretary General, LAUTECH Muslim Community.

He is currently the Head, Building Department, Team Leader, Cement and Concrete (CEMCON) Research Group, and Chairman, Board of Entrepreneurship Development Centre, LAUTECH, Ogbomoso. He is married to Alhaja Badirat Kehinde Raheem (FCA) and the marriage is blessed with wonderful children.

CITATION OF PROF. AKEEM AYINDE RAHEEM

The blooming of trees heralds the season of plenty. This is the metaphor for the birth of the astute academic, profound researcher, thorough-bread professional, great mentor, and respected community leader here standing before this great assembly of intellectuals. He is Professor Akeem Ayinde Raheem who was born on June 3, 1963, in the city of Lagos. His educational adventure started in Lagos in Progressive Primary School Surulere, as a pupil. He obtained B.Sc. (Honours) in Building from the University of Ife (Now Obafemi Awolowo University), Ile Ife in 1987 before proceeding to the University of Lagos, Akoka where he obtained M.Sc. (Construction Technology) in 1996 and then Ph.D. (Building Structures) in 2006 from Obafemi Awolowo University, Ile Ife.

He started his career as a Graduate Assistant in the Department of Civil Engineering, LAUTECH, Ogbomoso in 1992 and rose through the ranks and files of academic cadre to becoming a Professor of Building in the Department of Civil Engineering on October 1, 2013. His wealth of experience was built from various positions and capacities that he had served within and outside the university campus. Principally, he has served as the Ag. Head, Civil Engineering Department; Departmental Examination Officer, Departmental Postgraduate Programmes Coordinator, Deputy Dean, Faculty of Engineering and Technology; Chairman, Faculty Adhoc Building Committee, Chairman, Industrial Training and Placement Committee, Chairman, Local Organising Committee of the 2nd and 3rd International Conference on Engineering and Technology Research, Faculty of Engineering and Technology; Chairman, Faculty Time Table and Examination Committee, Chairman, Faculty Postgraduate Advisory Committee, Chairman, Faculty Induction Committee, Chairman, Faculty Lecture Series Committee; Chairman, Examination Invigilation Monitoring Team, Faculty of Engineering and Technology; Member, University Curriculum Committee; Member, Board of Postgraduate School; Chairman, Scholarship and Prizes Committee; and Chairman, Parents and Teachers Association, LAUTECH Staff School; to mention a few.

As an active researcher and project leader, he has led some funded research and has more than eighty (80) articles in reputable journals to his credit. He has successfully supervised Six (6) Ph.D. theses, fourteen (14) M. Tech. dissertations and over 500 B. Tech. Students' projects while many are on-going. He has served as an external examiner to the Civil Engineering Department, Osun State Polytechnic, Iree; Building Department, Obafemi Awolowo University, Ile-Ife; Building Department, Federal University of Technology, Minna; Civil Engineering Department, University of Ibadan, Ibadan; Civil and Environmental Engineering Department, Kwara State University, Malete, Ilorin; Civil Engineering Science Department, University of Johannesburg, South Africa; Civil and Environmental Engineering Department, The University of the West Indies, Jamaica; Civil Engineering Department, University of Abuja, Abuja and Building Department, University of Lagos, Akoka. He has served as Professorial Assessor to many Universities within and outside Nigeria. He has also taught at various levels as a Visiting Professor at the University of Lagos, Akoka; Building and Quantity Surveying Department, College of Environmental Sciences and Management, Caleb University, Lagos and Department of Civil and Chemical Engineering, University of South Africa, Johannesburg, South Africa. He has attended and presented papers at both local and international professional conferences. He has served as a reviewer to several national and international scientific and trade journals.

Prof. Raheem is a member of pertinent professional bodies and networks. He is a graduate member, Nigerian Society of Engineers; Corporate Member, Nigerian Institute of Building, and a Fully Registered Builder with CORBON. He is a member, Technical Committee on the proposed Muslim Hospital for Ogbomoso as well as member and later chairman, National University Commission (NUC) Accreditation Teams. In his quest to serve a larger community, he was a Facilitator, National Population Commission; WAEC Examiner in Building Construction; Member, Board of Trustee Igbo-Agboin Muslim Community; Treasurer, Challenge Landlords Association, Challenge area, Iwagba, Ogbomoso, Member, Board of Trustee Muslim Scholarship Fund Nigeria, and Secretary General, LAUTECH Muslim Community.

He is currently the Head, Building Department, Team Leader, Cement and Concrete (CEMCON) Research Group, and Chairman, Board of Entrepreneurship Development Centre, LAUTECH, Ogbomoso. He is married to Alhaja Badirat Kehinde Raheem (FCA) and the marriage is blessed with wonderful children.

PROTOCOLS

The Vice Chancellor
Registrar
Other Principal Officers
Chairman, Committee of Provosts and Deans
Provosts of Colleges
Deans of Faculties and Postgraduate School
Professors and other Members of the Senate
The Congregation and other Staff
Your Royal Highnesses
Members of my Family: Nuclear and Extended
Distinguished Invited Guests, Friends, and Well-wishers
Gentlemen of the Press
Greatest Ladokites
Ladies and Gentlemen

PREAMBLE

Glory be to Almighty Allah for making it possible for us to witness this day. It is a great honor and privilege for me to stand before you today 1st June 2023 to present the 54th Inaugural Lecture of this great citadel of learning – Ladoke Akintola University of Technology (LAUTECH) Ogbomoso; the best State University in Nigeria for several times. Today's inaugural lecture is the second in the Department of Civil Engineering and the first in the Department of Building where I am the Pioneer Head of Department.

This inaugural lecture is unique in that it is coming ten years after my promotion to the rank of Professor and having successfully supervised to completion, Six (6) Ph.D. Candidates. It also coincides with my 60th Birthday Anniversary.

IN THE BEGINNING

It was in September 1992, I was on my way back to Federal Government College (FGC) Wukari, Taraba State where I was teaching as Education Officer, to resume for the 1992/1993 academic session. I stopped at Ogbomoso to visit Mr. & Mrs. O.G. Bello working then at FGC Ogbomoso. We were colleagues at FGC Wukari before they got transferred to Ogbomoso. While ruminating about how I could also come down south due to the incessant crises in Wukari between Jukun and Tiv people, and because of the stress involved in transportation (to and fro), I was advised to check Ladoke Akintola University (LAUTECH), Ogbomoso for a possible vacancy. On Thursday, 10th September 1992, I visited Architecture Department, LAUTECH to seek employment. I met late Arch. Bello and Arch. Atolagbe, who informed me that there was no vacancy. They advised me to check Civil Engineering Department which was closed to them then at Physics Department Building being shared with Faculty of Engineering and Technology. On getting there, I was told that the Dean had traveled to Ibadan and I can only see him the following Monday. I was in a dicey situation. It is either I waited to see the Dean or traveled to Wukari to attend an earlier scheduled staff meeting to plan for resumption which our principal had seriously warned us not to miss.

I took the risk of waiting and I met the Dean then – Prof. E. B. Lucas who interviewed me the same day by giving me three (3) Technical Drawing Questions all of which I did well to his satisfaction. He assured me of an appointment if I could wait to see the Ag. Head of Civil Engineering Department then - Late Dr. G.A. Alade the following Wednesday. I met him as arranged and he was also satisfied. I returned to Wukari on 22nd September 1992. Two great events occurred in October 1992. First, I received my letter of appointment as Graduate Assistant at LAUTECH. Second, I got a query for not attending the scheduled staff meeting of 15th September 1992. I resigned from my appointment with FGC Wukari after receiving the query. The principal called me to his office to say that I was not the target, but the perpetual absentee. I had to inform him why I missed the meeting and the positive outcome of it. Thus, the journey to this day began on the 2nd of November, 1992 when I resumed as Graduate Assistant in the Civil Engineering Department as the first indigenous permanent academic staff.

1.0 INTRODUCTION

Shelter is the third most essential need of human beings after food and clothing according to Maslow’s hierarchy of needs. All animals seek an abode as shelter. The history of building dates back to the time of the Early man who sought shelter in a cave against the effect of severe weather (sunshine, rain, snow) and safety from wild animals. The presence of buildings is very vital to society as they serve various needs of society which include shelter from the weather, security, living space for various activities, privacy, to store belongings, and to live and work, comfortably.

Thus, a building can be described as a walled and roofed structure used for many various activities and which deteriorates throughout its lifespan (Olanrewaju *et al.*, 2011).

Owning a building is an important sociocultural aspect of humanity as indicated in a common saying in Yoruba which states that "*Eni ti o nile lori, asiri re ko tii bo*". Meaning: one without a personal house has his secrets in the open. This necessitates the need for affordable buildings irrespective of the economic status and population of the citizens especially those in third-world countries. It has been noted that poverty is one of the important factors that makes it difficult for most Nigerians to own their houses (Daramola *et al.*, 2005) because the costs of construction are beyond the reach of the poor masses who are predominantly salary earners with lean income or petty traders who are merely struggling to survive due to the unpleasant economic situations in the country.

Mr. Vice Chancellor sir, it is no gain saying that the shelter sought by man has led to destruction, penury, death, and detrimental sentimental impact. Sadly, building collapse, particularly those under construction, is becoming a norm in Nigerian towns and cities, and it is indeed very alarming in recent times. Records from various governmental agencies and published literature revealed that buildings collapse occurrences between 1974 and 2019 across various Nigerian cities and towns were in the hundreds. The percentage of occurrence for residential, commercial and institutional buildings, are 78.4, 12.8 and 8,8 percent, respectively (Olasunkanmi 2022). The Leadership Newspaper (September 2022) noted that over 460 buildings have collapsed in the country in the past four decades. It was observed that from 2011 to 2019, about 84 building collapse incidents were recorded, with 21 occurrences outside Lagos. The report indicated that 41 % of these incidents involved existing structures while 59 % were buildings still under construction. (https://leadership.ng/curbing-alarming-cases-of-building-collapse-in-nigerian-cities/). These ugly developments have consumed an estimated loss of property worth $3.2 trillion, displaced more than 6,000 households, and led to more than 1,000 deaths and many severe injuries (Olasunkanmi 2022). In all these, materials of construction and supervision of the process played a major role. This then indicates the dare need for reliable buildings.

The lifespan of a building depends largely on its design, construction and maintenance. Nigeria has had a disturbing history of unsustainable building practices, mismanagement of buildings and poor maintenance culture with no consideration for its impact on the environment. Buildings are the main physical assets of any nation and they are put in place to enhance the quality of life of the citizens, unfortunately, these buildings become liabilities if they are not properly planned and maintained in a sustainable manner. Lam *et al.,* (2010), noted that fifty percent of all annual construction activities were exclusively for building maintenance in the United Kingdom from the year 2002. However, this is not the case in Nigeria, where there is poor maintenance culture and values with a high record of poor performance operations (Abigo *et al*., 2012). The sustainability of building performance, therefore, demands great attention and becomes an invaluable process in retaining the value and quality of a building.

Mr. Vice Chancellor sir, it can be deduced from the foregoing that there is a strong desire for economic advantage, quality assurance, safety and bearable building from its design to construction, operation, maintenance, renovation or reconstruction. The quest to satisfy this desire elicited the title of today's lecture, "**Affordable, Reliable and Sustainable Buildings: Innovative Construction Materials as Panacea"**

Reliable buildings are those that can stand the test of time. They are buildings that you can sleep inside with your two eyes closed. This means that the structure must effectively support both the dead and imposed loads. The dead load concerns the self-weight of the materials of construction while the imposed load deals with occupational activities to be housed in the building. Thus, there is a need for adequate structural design of a building to balance both the dead and imposed loads with the bearing capacity of the soil on which it is built. The aim of the structural design of a building is to ensure that the structure will be safe and economical to build and perform satisfactorily throughout its life (Raheem and Adewuyi, 2007). There should be no fear of collapse or whatever failure during construction and while hibernating in a building.

Sustainability involves creating an enduring future that considered environmental and social factors simultaneously with economic factors. Sustainable development means meeting the needs of the present without compromising the future. Thus, sustainable housing is that which is within the financial reach of individuals and which matches their aspirations.

According to Ayangade *et al.* (2004), the cost of materials accounts for two-third of the total building production cost. A reduction in the cost of materials would bring about a huge saving in the overall cost of constructing a building. Materials for construction purposes can be classified as conventional, local or innovative materials. Conventional materials are mostly imported thus, very expensive. Local materials are sourced within the locality of construction; they are cheaper but not readily acceptable by many due to ego matters. Innovative materials try to strike a balance between the former and the later through extensive research on local materials, to improve their standards and make them affordable. Olusola and Adesanya (2004), identified astronomical increases in prices of conventional building materials as one of the constraints to effective housing delivery in Nigeria. According to Osunade (2002), as prices increase sharply, there is a need to search for local materials as alternatives for the construction of functional but low-cost buildings in both the rural and urban areas of Nigeria.

Various research efforts had been undertaken on the use of locally available materials as alternatives for conventional materials with a view to reducing the cost of building (Adesanya, 1993; 1996; 2000; 2001; Adeyemi, 1998; Okafor, 1998; Omange, 2001 and Osunade, 2002). According to Olusola and Adesanya (2004), the research findings have not gone beyond the researcher's desk in terms of implementation of the laudable results obtained due to certain factors among which are:

- Non-acceptability of the new materials by the targeted users.
- Lack of technological base for mass production of the materials
- Lack of sponsorship from government and industries to market the new product.
- Lack of coordination among research institutes, higher institutions, and government/private organizations in harnessing the research efforts and developing them to meet world standards.

With the shortcomings highlighted above, there is a need to look inward and consider how the cost of the most used conventional materials such as cement and aggregates could be reduced to an affordable level without compromising standards. This brings about the development of I**nnovative Construction Materials** which had been the focus of our research for about three decades.

Concrete is the most used construction material throughout the world. There has been an increasing use of concrete in construction industries worldwide due to its excellent mechanical properties. As a result of the high demand for concrete, the main ingredients – cement and aggregates, are becoming very expensive to procure. There are also negative environmental impacts brought about by the production of conventional materials. According to Flower and Sanjayan (2007), for every 1.0 t of cement produced, 0.8 t of CO_2 was emitted. In the same vein, the depletion of natural resources could be caused by the excessive use of conventional aggregates (granite, gravel, etc.) and their quarrying could lead to environmental issues (Blankendaal *et al.*, 2014).

The search for alternative materials for concrete led to the investigation of agricultural residues as supplementary materials in mortar and concrete. Agricultural residues are waste products obtained after the consumption, processing or use of agricultural products. On harvesting and consumption of some agricultural products such as corn or maize, groundnut, coconut and sugarcane; abundant wastes are left behind such as corn cobs, groundnut shells, coconut shells and sugarcane bagasse. Also, the processing of some agricultural products such as timber, palm oil, and rice led to the generation of wastes such as sawdust, palm kernel and rice husk. These materials are readily available, less expensive, easily processed and exhibit good reactivity in concrete; hence, the increase in the attention given to them by researchers. Effective use of these materials in concrete will result in green method of disposal of large quantities of these wastes, which would otherwise have caused environmental nuisance. These residues are mainly used as supplementary cementitious materials and aggregate replacement in concrete.

My research focus can be grouped into four main categories as follows:

(i) Safety of buildings and infrastructures,

(ii) Studies on locally available construction materials,

(iii) Applications of Supplementary Cementitious Materials (SCM), and

(iv) Improvements in the Characteristics of SCM.

2.0 SAFETY OF BUILDINGS AND INFRASTRUCTURES

Mr. Vice Chancellor sir, the journey to my research world commenced when I decided to go for my Master's degree in Construction Technology at the University of Lagos. I was assigned to Associate Prof. M.B. Olufowobi for my M.Sc. dissertation. Being an expert in Building Services, I had to select a research topic in his area of specialization, a decision that assisted me in completing my programme on schedule.

Safety consideration is essential in all buildings and infrastructures inhabited by people. You want to stay in your house and feel secure from both internal and external threats. Insecurity could result from defective structural integrity during construction and the service life of the structure. Both, if not adequately attended to, could lead to colossal loss of lives and properties.

Raheem (2001) examined fire safety in highrise residential buildings. Four notable highrise buildings in Lagos State were selected for case study. They are:

(i) Ikoyi Tower – situated along Oba Oyekan avenue, off Muritala Mohammed way, Ikoyi Southwest;

(ii) Bar Beach Tower- located along Bishop Oluwole street, off Ahmadu Bello way, Victoria Island;

(iii) Eric Moore Tower – positioned along Eric Moore Road, off Bode Thomas Street, Games village, Surulere; and

(iv) Eko Court Flats – standing at the junction of Ozumba Mbadiwe avenue and Akin Odesola street, Victoria Island.

The study was carried out through physical observation of the buildings, administration of questionnaires to occupants and oral interviews of fire personnel. A checklist was formulated to compare the fire safety provisions in each of the buildings selected for the case study with the standard requirement for highrise buildings based on the available code of practice. The study revealed that all the selected case studies are satisfactory only in terms of passive safety measures using adequate construction materials, availability of proper access roads and provision of suitable number and size of exit doors. However, the buildings are not satisfactory in terms of active safety measures as necessary provisions for fire detection and first aid fighting are either lacking or non-functional. It was concluded that concrete measures need to be taken right from the design stage to forestall an outbreak through the provision of adequate means of escape, installation of an effective and functional system of fire detection and alarm, and provision of first aid fire-fighting equipment.

Raheem and Wabara (2002) investigated the causes of accidents on building construction sites. The study was carried out through an extensive field survey incorporating the use of questionnaires and structured oral interviews. The study was limited to sites within Lagos State as greater part of construction works exist there. The study revealed that carelessness on the part of construction workers is the major cause of accidents on building sites as it accounted for about 94% of the different causes recorded. Also, lack of adequate supervision accounted for 69% of the causes - due to the absence of qualified personnel on-site. The most frequent type of accident is stepping on, or striking against objects, which accounted for 55% of the total number of accidents recorded, while exposure to electric current with 2.2% is the least frequent. It was concluded that in order to minimize the occurrence of accidents on building construction sites, the measures to take include maintaining a tidy site, adequate supervision by qualified personnel, regular use of protective devises, adequate safety training and avoiding excessive overtime for site workers.

In a study by Olufowobi and Raheem (2004), an assessment of the fire safety of University of Lagos Highrise building and 1004 Flats in Lagos State was carried out. This was through physical observation of the buildings, administration of questionnaires to occupants and oral interviews of fire personnel. A checklist was formulated to compare the fire safety provisions in each of the buildings with the standard requirement for high-rise buildings based on the Lagos State Town and Country Planning (Building Plan) Regulation (1986) and the British Guide to Fire Precaution in Hotels and Boarding Houses, Part 2: 1971. The study revealed that the buildings considered lack the necessary provisions for fire safety in terms of design and fire installations. More than 60% of the items considered for each building were not satisfactory. Due to many occupants and the risk of sleeping involved, it was concluded that adequate architectural and structural design, use of non-combustible construction materials, provision of adequate means of escape, installation of an effective and functional system of fire detection and alarm, fire safety training and provision of functional fire-fighting equipment are necessary to upgrade the fire safety of the buildings.

The Construction Industry has certain peculiarities among which is the fact that work is carried out in the open and subject to vagaries of weather. Due to the uniqueness and complexity of the industry, it has a high rate of accidents which constitutes a constant drain on the industry’s scarce resources. As a result, Raheem (2004) evaluated the occurrence of accidents on road construction sites. Field surveys incorporating the use of questionnaires and structured oral interviews were carried out on limited sites within Oyo and Kwara States. The study indicated that the highest rate of accidents on road sites occurred during earth movement and pavement construction operations. This could be attributed to the use of heavy plants and equipment during these stages. It was also revealed that non-usage of protective devices by workers is the major cause of accidents on road construction sites as it accounted for about 70% of the different causes recorded. The most frequent type of accident is struck or cut by materials or objects, which accounted for about 62% of the total number of accidents recorded, while exposure to explosion blast with 6.4% is the least frequent. To minimize the occurrence of accidents on road sites, measures recommended include regular use of protective devices, adequate safety training, avoiding excessive overtime for site workers and the development and use of a safety program for each job.

The use of construction equipment has been identified as a major contributor to the occurrence of accidents in the construction industries in Nigeria. Adebiyi and Raheem (2011) examined safety practices in the use of construction equipment by selected construction industries in Oyo, Kwara and Lagos States. Data were collected on injury and accident occurrence on the use of selected equipment from four multi-national construction companies with organized safety programmes. The commonly used construction equipment investigated are bulldozers, graders, excavators and pay loaders. The study was carried out using structured questionnaires, interviews, technical checklists, and physical observations. Four causes of accidents were identified as equipment design, maintenance, human/personal factors, and work issues. The results showed that most of the equipment being used was of age. It was also found that inadequate Protective Personal Equipment (PPE), low literacy level of operators, excessive overtime, inadequate safety training, inefficient work supervision and poor maintenance culture are prevalent in all the industries considered. The safety practices in the four companies exhibit similar traits. It was concluded that safety regulation enforcement is essential to prevent alarming accident occurrences in construction sites.

3.0 STUDIES ON LOCALLY AVAILABLE CONSTRUCTION MATERIALS

Mr. Vice Chancellor sir, my foray into construction materials commenced when I was searching for a research topic for my PhD thesis. I had made up my mind to work on concrete which is a versatile material used for construction purposes. The challenge then was how to come up with something that will be beyond the ordinary. The idea of exploring locally available materials first came to mind. This later transmuted into the application of innovative materials in concrete production. However, conventional concrete needs to be fully understood through various investigations of its constituents and characteristics of the fresh and hardened product.

Simply put, concrete is a mixture of cement paste and aggregates. Cement provides the binding medium while aggregates give volume and strength to the concrete. Two types of aggregates are used in concrete production namely: fine and coarse aggregate. Fine aggregates are those that pass through a 4.75mm square-mesh sieve while coarse aggregates are those retained on it. The nominal maximum size of coarse aggregate used for any work depends on the dimensions of the structural member in question. A basic rule is to ensure that the maximum aggregate size does not exceed the concrete cover to reinforcement or 25% of the minimum thickness of the concrete member (Kong and Evans, 1987).

Raheem and Aderounmu (2002) investigated the effect of coarse aggregate sizes on the compressive strength of concrete. Three classes of concrete were produced with sizes of the coarse aggregate varying as follows:

(i) Class A concrete – with aggregate size between 4.75 and 9.5 mm

(ii) Class B concrete – with aggregate size between 9.5 and 25.0 mm

(iii) Class C concrete – with aggregate size between 25.0 and 37.5 mm

The concretes were cast into 150 mm cubes which were crushed at curing ages 3, 7, 14, 21 and 28 days to determine their compressive strengths. The results indicated that Class A concrete – with a maximum aggregate size of 9.5 mm, has a mean compressive strength of 18.97Nmm^{-2}, Class B concrete with a maximum aggregate size of 25.0 mm, has a mean compressive strength of 22.37

Nmm^{-2} and Class C concrete with a maximum aggregate size of 37.5mm, has a mean compressive strength of $18.07Nmm^{-2}$ at maturity age of 28 days. It was concluded that the compressive strength of concrete increases with an increase in sizes of coarse aggregate up to a maximum of 25mm. This result showed that with larger aggregates, there is no adequate bonding between the aggregate and cement paste, hence the decrease in strength.

With the influx of different brands of Ordinary Portland Cement (OPC) into the country, there is a need for an in-depth study of the characteristics of concrete produced using these brands of cement to ascertain their quality. In a study by Adesanya and Raheem (2002), compressive strength being the most valuable property of concrete was employed as the means of assessing the quality of the various brands of OPC used for its production. Five different brands of OPC were considered namely: Burham. Dangote, Elephant, Gateway and Santex. Two different mix ratios were considered namely; 1:2:4 and 1:3:6. It was observed that the mean compressive strengths at 28 days for all five brands of cement were very close. For the 1:2:4 mix ratio, Dangote cement concrete has the highest compressive strength of 24.46 Nmm^{-2} while Elephant cement concrete has the lowest compressive strength of 24.30 Nmm^{-2}. Similarly, for the 1:3:6 mix ratio, Santex cement concrete has the highest compressive strength of 19.78 Nmm^{-2} while Gateway cement has the lowest compressive strength of 19.59 Nmm^{-2}. Burham Cement was also observed to have a faster rate of hardening when compared with other brands. It was concluded that there is no significant difference in the compressive strength of concrete produced with the different brands of Ordinary Portland Cement. Also, Burham cement is recommended for use where early strength development is required.

This strength of concrete depends on several factors ranging from the properties and proportions of the constituent materials to the testing conditions. Raheem and Abimbola (2006) examined how the size of test specimens affects the compressive strength of concrete. Three different sizes of concrete test specimens of 100 mm cubes, 150 mm cubes and 150 x 300 mm cylinders were prepared from three different mix ratios: 1:1½:3; 1: 2:4 and 1: 3: 6 and subjected to compressive strength test at the ages of 7, 14 and 28 days. The result revealed that 100mm cube specimens had the highest average compressive strength for each of the three mix ratios, followed by 150mm cube specimens while cylinder specimens had the least average compressive strength. Thus, it was concluded that the smaller the size of the concrete test specimen, the higher the compressive strength. The implication of this is the economy of the material required in preparing test specimens.

The effect of different methods of curing on the density and compressive strength of concrete was also considered by Raheem *et al*. (2013). Concrete cube specimens of mix 1:2:4 were prepared with a water-cement ratio of 0.65. The cubes were cured using six methods (air curing, water-submerged curing, spray curing, polythene curing, moist sand curing and burlap curing) until testing ages of 3, 7, 14, 21 and 28 days when their densities and compressive strengths were determined. The results showed that the densities of the specimens ranged from 2432.59 to 2502.72 kg/m^3. The burlap curing method has the least standard deviation in the density of specimens. Also, the moist sand curing method produced concrete specimens with the highest 28-day compressive strength of 30.5N/mm^2 followed by the burlap curing method with a value of 24.4N/mm^2. Air curing had the lowest 28-day compressive strength of 17.8 N/mm^2. All the curing methods except air-curing, produced specimens that met minimum compressive strength requirements in the available code. It was concluded that there exists a weak but positive correlation between the density and compressive strength of concrete specimens.

Dwellers along the coastline area of Lagos State, Nigeria, are exposed to an abundant supply of the natural resources of the Atlantic Ocean and Lagoon water and may not have the privilege of having potable drinking water at their disposal for producing concrete. Raheem *et al.* (2013) evaluated the characteristics of concrete produced in the Atlantic Ocean and Lagoon water. Concrete produced with Tap water (regarded as potable or drinking water) serves as the control experiment. Compressive strength, Workability and Density, were used to evaluate the characteristics of concrete specimens. All the concrete samples had true slump with Lagoon water concrete having low workability while both Tap and Atlantic Ocean water concrete had medium workability. The concrete specimens produced with the three types of water fall into the category of normal weight concrete as their densities lie within the range of 2200 to 2600 kg/m^3 specified. For mix ratios 1:3:6 and 1:2:4, the 28th-day compressive strength of concrete specimens produced with Atlantic Ocean, Tap and Lagoon water were 25.0 and 33.5 Nmm^{-2}, 17.9 and 28.6 Nmm^{-2} as well as 15.1 and 19.4 Nmm^{-2}, respectively as indicated in Figures 1 and 2. The very high compressive strength of concrete specimens produced with Atlantic Ocean water notwithstanding, the high chloride content in it is detrimental to its use where reinforced steel bars are required. It was concluded that Tap water should be used in mixing concrete where strength is of major concern and Lagoon water may be used for general concrete works where strength is of less importance such as in mass concrete, floor screed and mortar.

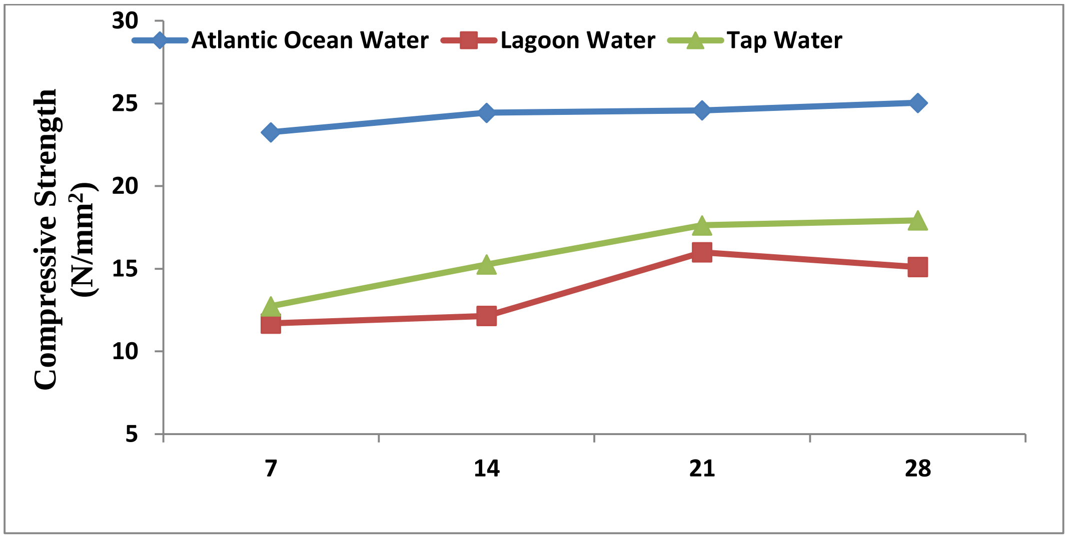


Figure 1: Effect of Mixing Water on the Compressive strength (Mix ratio 1:3:6 Concrete)

Age (Days)

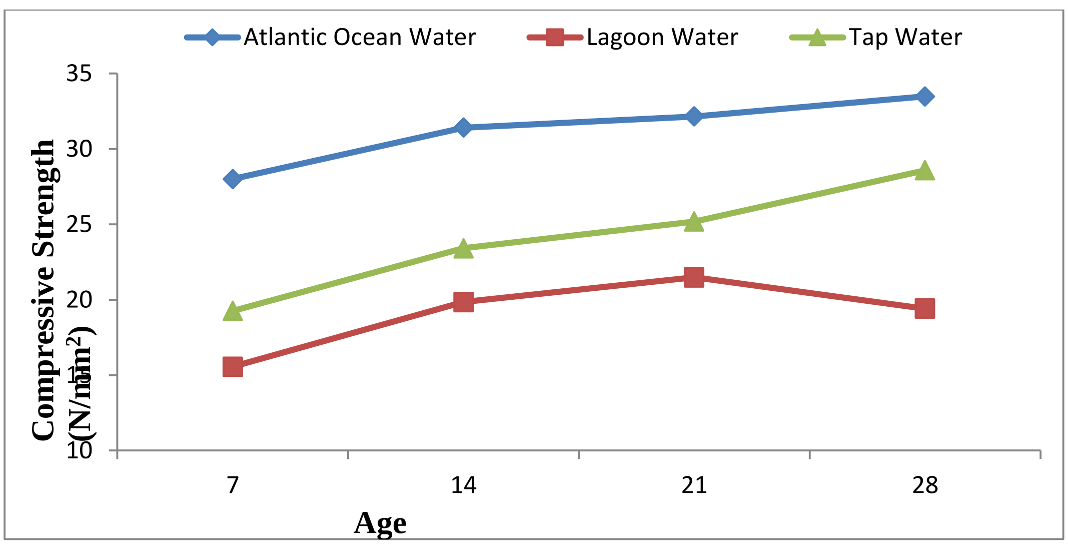


Figure 2: Effect of Mixing Water on the Compressive strength (Mix ratio 1:2:4 Concrete)

Granite is the most used coarse aggregate material for producing good concrete. However, it is very expensive and sometimes not available. Gravel is the locally available coarse aggregate but it's not as strong as granite. The viability of combining gravel and granite in concrete production was assessed by Raheem and Bamigboye (2013). Concrete was produced using a granite/gravel combination in varying percentages of 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20/80 and 10/90. Concrete made from 100 % granite and 100 % gravel served as controls while other constituents of the concrete were kept constant. Two different mix ratios of 1:2:4 and 1:3:6 were employed. Concrete specimens were produced using 150 mm cubes and 150 mm x 300 mm cylinders for compressive and tensile strength tests, respectively. The results indicated that the reliable percentage of granite/gravel combination from a compressive strength viewpoint is 60/40 with a value of 21.15 Nmm^{-2} for mix ratios 1:2:4 and 70/30 with a 15.17 Nmm^{-2} for a 1:3:6 mix ratio. The minimum requirement of 20 and 15 Nmm^{-2} for 1:2:4 and 1:3:6 mix ratios respectively as specified by BS 8110: Part 1 (1997) were satisfied (figures 3 and 4). The splitting tensile strength of 70/30 percentage of granite/gravel combination for 1:2:4 and 1:3:6 mix ratios were 10.50 and 4.70 Nmm^{-2}, respectively. From the findings of this study the following conclusions were arrived at:

(i) The workability of concrete increases with an increase in the percentage of gravel content,

(ii) The density of concrete decrease with an increase in the proportion of gravel,

(iii) The compressive strength of concrete produced from the combination of granite and gravel as coarse aggregates decrease as the proportion of gravel increases. The percentage of granite/gravel content that satisfied the minimum strength requirement at 28days for 1:2:4 and 1:3:6 mix proportions are 60/40 and 70/30 respectively and

(iv) For tensile strength, the reliable percentages of granite/gravel content satisfying the minimum strength requirements at 28 days for 1:2:4 and 1:3:6 mix ratios are 60/40 for both mixes.

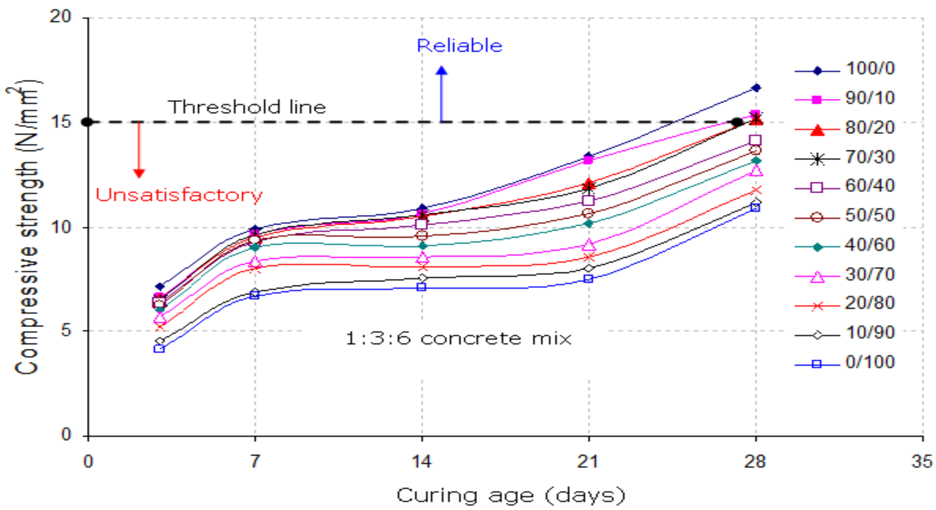


Figure 3: Variation of compressive strength of concrete cubes for different granite/gravel combinations (mix ratio 1:3:6)

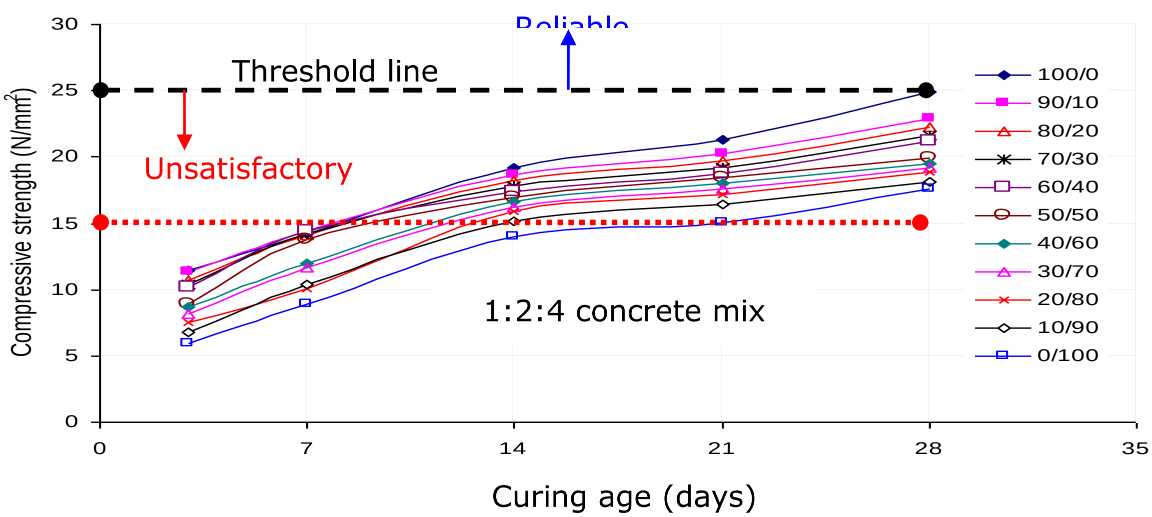


Figure 4: Variation of compressive strength of concrete cubes for different granite/gravel combinations (mix ratio 1:2:4)

Bamigboye *et al.* (2016) assessed the economic exploitation of gravel in place of granite in concrete production. Empirical evidence from the regression analysis revealed that higher composition of gravel significantly improves the concrete consistency properties while greater proportions of granite significantly enhance comprehensive strength. An economic saving of about 3.5% and 4% was realized per unit volume of concrete production for 1:3:6 and 1:2:4 mix proportions respectively.

In places where agricultural residue such as palm kernel shells are abundant, they could be used as a partial replacement for aggregates in concrete. Effective use of these materials in concrete will result in a green method of disposal of large quantities of waste, which would have caused environmental nuisance. Raheem *et al*. (2008) considered the effect of replacing sharp sand and granite with palm kernel shell (PKS), on the properties of concrete. Compressive strength, density and workability were used to determine the qualities of two categories of concrete produced using palm kernel shells as coarse aggregates on one hand, and fine aggregates on the other. The percentage replacement of Aggregate with PKS considered were: 75:25, 50:50, 25:75 and 0:100 in terms of PKS: Aggregates. The 0:100, which is the control, indicates 100% granite or sand as the case may be. Ordinary Portland cement was used as the matrix. The results indicated that the density and compressive strength of the concrete decreased as the percentage substitution of PKS for granite or sand increased. Higher density and compressive strength values were recorded when PKS was used as a fine aggregate. Also, the 25% PKS replacement level is the most practicable as it exhibits similar characteristics to that of the control. It was concluded that PKS is more suitable for use as a percentage replacement for fine aggregates.

With the continuous depletion of available deposits of igneous rock because of its numerous uses in Building and Civil Engineering works, the suitability of Recycle Iron and Steel Slag (RISS) aggregate as an alternative to granite aggregate was considered. Raheem *et al.* (2021a) assessed the mineralogical composition of RISS and granite aggregates and determined the effects of RISS aggregate on the flexural strength of concrete beams of 150 × 150 × 600 mm containing 10, 20, 40 and 60% RISS aggregate replacement in mix ratios 1:1½:3, 1:2:4 and 1:3:6 with water-cement ratios 0.65, 0.60 and 0.55, respectively. X-Ray Diffractograph of RISS and granite aggregate showed that RISS contains Magnetite, Ilmenite and Quartz, while granite contains Quartz, Annite, Microcline and Albite as the predominant minerals. Both aggregates contained quartz as the most predominant mineral and were well-graded. The result of the flexural strength at 28 days of curing is within 0.135 – 0.250 MPa specified by BS 8500 – 2 (2015). The flexural strength of concrete beams cast with partial RISS aggregate replacement was relatively higher than concrete cast with only granite aggregate. Thus, flexural strength which is a measure of the tensile strength of concrete was improved as the percentage of RISS aggregate replacement increased.

The effects of water-cement ratios on the strength characteristics of concrete produced with Recycled Iron and Steel Slag (RISS) aggregates were also investigated by Raheem *et al.* (2021b) in order to ascertain the structural integrity of RISS aggregate in concrete and to determine the veracity of RISS aggregate as alternative aggregate to granite in concrete works. Concrete specimens were prepared with 10, 20, 40 and 60% RISS aggregate replacement in mix ratios 1:1½:3, 1:2:4 and 1:3:6 using water-cement ratios (WCR) 0.65, 0.60 and 0.55. The results indicated that the compressive and flexural strength increase as the WCR decreases and reduces as the WCR increases. Thus, the reduction of the water-cement ratio improves the compressive and flexural strengths of RISS aggregate concrete.

The characteristics of concrete may be affected by the sources from which the aggregate was obtained. The effects of granite sourced from four selected locations within Ogbomoso, Nigeria; on the fresh and hardened properties of concrete were studied by Raheem *et al.* (2021c) The granites were obtained from: Asafa (8^0 4.68^1 N and 4^0 20.78^1 E), Ola-Jesu (8^0 13.59^1 N and 4^0 10.1^1 E), Igbo-Ile (8^0 4.68^1 N and 4^0 19.57^1 E) and Apasu (8^0 14.96^1 N and 4^0 10.05^1 E) quarries. Sieve analysis, specific gravity, moisture content, Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) of the granites were determined. The aggregates were used to produce concrete of two different mix ratios- 1:2:4 and 1:3:6. Slump and compaction factor tests were carried out on fresh concrete and compressive strength, splitting tensile strength and water absorption on hardened concrete. The results indicated that for both concrete mixes, granite obtained from Asafa and Ola-Jesu exhibited improved characteristics over those sourced from Igbo-Ile and Apasu and is more suitable for use in producing good-quality concrete. Crushed granite from the Asafa Quarry Site is the best for producing high-quality concrete.

The rate at which concrete structures especially buildings are gutted by fire hazards is on the increase and this has an adverse effect on the residual strength, hence, the need to assess the post-fire structural strengths of Normal Strength Concrete (NSC). Raheem *et al.* (2015) assessed the post-fire structural strengths of NSC subjected to cyclic thermal loadings. NSC of grade 50 was produced and cast into specimens of sizes 150mm cubes and 100mm x 100mm x 500mm reinforced concrete beams. The concrete cubes and beams were subjected to elevated cyclic thermal loadings after 7, 14 and 28 days of curing, while the rate of heating was maintained at 1°C/min until the target temperature of (100, 130, 160, 200 and 250) °C were attained and this was maintained for one hour and then allowed to cool at 1 °C/min to room temperature of 32 °C. Unstressed Residual Uniaxial Compressive Test (URUCT) and Flexural Strength Test (FST) were conducted on the cubes and reinforced concrete beams, respectively. Direct Tensile Strength Test (DTST) was performed on the high-yield (460 Nmm^{-2}) steel reinforcement. The result showed that the residual compressive strengths of concrete cubes decreased with increasing thermal loadings. The expected strengths of 0.69 and 0.97 of the 28 days strength for 7 and 14 days respectively were met. The flexural strengths decreased with an increase in thermal loadings. The flexural strength of the concrete beams at 28 days of 15.25 Nmm^{-2} at thermal loading of 32 °C was reduced to 8.16 Nmm^{-2} at thermal loading of 160 °C; while the strength at 14 days of 12.19 Nmm^{-2} at thermal loading of 32°C was reduced to 7.62 Nmm^{-2} at thermal loading of 160 °and finally, the strength at 7 days of 10.13 Nmm^{-2} at thermal loading of 32 °C was reduced to 5.82 Nmm^{-2} at thermal loading of 160 °C. All the results met the specification for high-yield steel of 12% elongation at fracture. It was concluded that within the thermal loading range adopted, the tensile strength of the reinforcement was not impaired beyond the limit specified by the code.

Another local material used for building is sandcrete blocks which are mainly employed for wall construction. Being easy to set up and due to the fast returns from the business, a lot of blocks making industries usually spring up at every nook and cranny of the country. Thus, the quality of the blocks produced is questionable. Raheem (2006) considered an assessment of the quality of sandcrete blocks produced by LAUTECH Block Industry an arm of LAUTECH Ventures, and those produced by selected block industries within Ogbomoso town. The study was carried out through laboratory tests on some units of blocks produced by LAUTECH Block Industry and block samples obtained from twenty (20) block industries within Ogbomoso township, to determine their compressive strength and density. The results obtained indicated that for blocks produced by LAUTECH block industry, the compressive strength of 450 x 225 x 225mm (9 inches) blocks increased from 0.54 Nmm^{-2} at age 3 days to 1.68 Nmm^{-2} at age 28 days, while that of 450 x 225 x 150 mm (6 inches) blocks increased from 0.53 Nmm^{-2} at age 3 days to 1.59 Nmm^{-2} at age 28 days. About 60% of the compressive strength at 28 days was developed at day 7 for both 9- and 6-inches blocks. For blocks obtained from the field survey, the compressive strength ranges from 0.28 Nmm^{-2} to 1.66 Nmm^{-2} for 9 inches blocks and 0.19 Nmm^{-2} to 1.55 Nmm^{-2} for 6 inches blocks. The density of the blocks produced in LAUTECH ranges from 2040 kg/m^3 to 2130 kg/m^3 for 9 inches blocks and 2000 kg/m^3 to 2110 kg/m^3 for 6 inches blocks, while for blocks obtained from field survey, it ranges from 2000.4kg/m^3 to 2115.3 kg/m^3 for 9 inches blocks and 1972.5 kg/m^3 to 2095.8 kg/m^3 for 6 inches blocks. These values are above the minimum density of 1500 kg/m^3 recommended for first-grade blocks. It was concluded that the blocks produced by LAUTECH block industry are of higher quality than those produced by about 90% of the selected block industries within Ogbomoso Township.

Two-cell hollow sandcrete blocks constitute the dominant wall construction material for modern shelter in many African countries, especially Nigeria. The hollow cavities in the block have an adverse effect on its mechanical characteristics. Olagunju and Raheem (2021) examined the effects of hollow sizes on the properties of sandcrete blocks. Sandcrete blocks of size 225 × 225 × 450 mm (9 inches) with varying hollow sizes of 175 × 187.5, 173 ×190 and 180 × 210 mm and web thicknesses 25, 35 and 15 mm, respectively were produced using cement to sand ratio of 1:12. The blocks were tested for compressive strength, density, and water absorption. The results indicated that compressive strength at 28 days for blocks with hollow sizes 175 × 187.5, 173 ×190 and 180 × 210 mm are 5.22, 3.64 and 0.41 Nmm^{-2}, respectively. The corresponding densities are 2307.56, 2589.15 and 1715.23 kg/m^3 while the rates of water absorption are 22.2, 18.8 and 24.5%, respectively. From the findings in this study, it could be concluded that the sizes of hollows in sandcrete blocks have a significant influence on the characteristics of the blocks in terms of density, compressive strength and water absorption. Large hollow sizes are preferred by block producers due to savings in materials cost. However, this has adverse effects on the properties of the blocks thereby reducing their quality. In order to use sandcrete hollow blocks as a structural material in walls, the minimum standards on the size of the hollow specified by the National Building Code (2006) and NIS 87 (2007) should be strictly adhered to for the safety of the workforce and occupants of the building.

Laterite is another material that can be used for block production especially where it is in abundant supply. Before it can be used, however, its characteristics need to be examined to assess its suitability. Raheem *et al.* (2010a) examined the engineering properties of some laterite found in

Ogbomoso in South-western Nigeria. As of then, Ogbomoso land comprised four Local Government Areas (LGA). Laterite samples were collected from Aroje in Ogbomoso North LGA, Randa in Ogbomoso South LGA, Idi-Iroko in Surulere LGA and Tewure in Orire LGA. The following tests were carried out on the samples to determine their engineering properties: Particle size distribution, Atterberg limits and Falling head permeability. The results obtained show that, the Aroje sample is an A-2-7 soil, while the other three samples belong to A-7-5 according to the AASHTO classification system. The group index values of the soils are 2, 16, 4, and 12 for Aroje, Randa, Idi-Iroko and Tewure samples, respectively. For all samples, the granular composition of the soil was found to be gravel: 6-25%, sand: 29-47% and fines: 30-49%, while the liquid limits ranged from 42-50%, plastic limits ranged from 10-25% and plastic index ranged from 16-39%. The coefficient of permeability of these soil samples ranged from 2.25-4.13 x 10^{-9} m/s. Federal Ministry of Works and Housing specifications for roads and bridges (1997) and TRL conventional specifications were used to determine the suitability of the samples as construction materials. The samples are suitable as fill material but the sample from Aroje is the most suitable as subgrade material followed by the sample from Idi-Iroko.

The production and testing of cement-stabilized lateritic interlocking blocks (LIB) were examined by Raheem *et al.* (2012a). The experiments involved the production of 250 × 130 × 220 mm interlocking blocks with laterite samples obtained from Aroje (Ogbomoso North LGA), Olomi (Ogbomoso South LGA), Idi-Oro (Surulere LGA) and Tewure (Orire LGA) using a locally fabricated manual steel mould and a 4.5 kg rammer. The blocks were tested in the laboratory to determine their 'compressive strength, water absorption and resistance to abrasion. The results indicated that all the stabilised blocks satisfied the minimum 28-day wet compressive strength of 1.0 Nmm^{-2} recommended by the Nigeria Building and Road Research Institute. The minimum seven-day dry compressive strength for 5% cement-stabilized blocks of not less than 1.60 Nmm^{-2}, as recommended in the National Building Code, was not satisfied by all the blocks. However, with 10% cement stabilisation, blocks from Olomi and Idi--Oro laterites satisfied the minimum 7-day strength with values of 2.13 Nmm^{-2} and 1.62 Nmm^{-2}, respectively. Only laterites from Olomi and Idi-Oro that met the minimum seven-day requirements were concluded to be suitable for the production of interlocking blocks in Ogbomoso, Southwestern Nigeria. Figure 5 shows the laterite interlocking blocks produced.

Figure 5: Stacking of Lateritic Interlocking Blocks

This technique of building with interlocking blocks eliminates the need for mortar in walling units and consequently leads to a further reduction in building costs. The tongs and grooves in the LIB serve as a key to bind the units together firmly. With improved technology, the hollows are made along both vertical and horizontal axes to provide additional rigidity. The red colour of the laterite is also an added advantage in that plastering and painting could be eliminated.

Raheem *et al.* (2010b) reported the results of a comparative study of cement and lime-stabilized lateritic interlocking blocks produced with laterite samples from the Olomi area in Ogbomoso, Oyo State, Nigeria. The stabilizing agents were added at 5, 10, 15, 20 and 25% by weight of lateritic soil. The blocks were tested for compressive strength, water absorption, and abrasion resistance. The results showed that average dry compressive strength at 28 days for cement-stabilized blocks at 5, 10, 15, 20 and 25% stabilization were 1.63, 2.60, 2.78, 2.82, and 3.12 Nmm^{-2}, respectively, while those of lime-stabilized blocks were 0.92, 1.25, 1.15, 1.06, and 0.94 Nmm^{-2}, respectively. The Nigeria Building and Road Research Institute (NBRRI, 2006) specified that the minimum 28 days strength should not be lower than 2 Nmm^{-2}. Only cement-stabilized blocks satisfied this requirement at 10% and above the stabilization level. It was concluded that cement-stabilized interlocking blocks are of better quality in terms of strength development.

Raheem *et al.* (2012b) considered the production and testing of sandcrete hollow blocks and laterite interlocking blocks with a view to comparing their physical characteristics and production cost. Some units of sandcrete hollow blocks and laterite interlocking blocks were made using machine-vibrated sandcrete block mould and hydraulic interlocking block-making machines respectively. The blocks were tested to determine their density and compressive strength. The results obtained from the tests were compared with the specifications of the Nigerian Building and Road Research Institute, NIBRRI (2006), Nigerian Building Code (2006), and NIS 87 (2007). The results indicated that the compressive strength of 225 mm and 150 mm sandcrete hollow blocks varies from 1.59 to 4.25 Nmm^{-2} and 1.48 to 3.35 Nmm^{-2}, respectively, as the curing age increases from 7 to 28 days. For laterite interlocking blocks, the strength varies from 1.70 Nmm^{-2} at 7 days to 5.03 Nmm^{-2} at 28 days. All the blocks produced satisfied the minimum requirements in terms of compressive strength, by all available codes. The cost per square metre of 225 mm and 150 mm sandcrete hollow blocks were ₦2,808:00 and ₦2,340:00, respectively, while that of laterite interlocking blocks was ₦2,121:20. It was concluded that laterite interlocking blocks have better strength and are cheaper than sandcrete hollow blocks.

Olowu *et al.* (2014) considered the production of improved stabilized lateritic Bricks (ISLB) with enhanced mechanical properties. Three batches of 290mm x 140mm x 100mm brick samples were produced which are: the Adobe Unstabilized Lateritic Bricks (AULB), Improved Stabilized Lateritic Brick (ISLB) and the Control Stabilized Lateritic Bricks (CSLB). Brick stabilization was maintained at 5% by the weight of cement. Compaction of the bricks was carried out manually; the moulded bricks were carefully extruded in good shape and placed on clean, hard flat surface to allow them to dry under normal atmospheric temperature and pressure. The ISLB was divided into four groups of 12 bricks samples immersed in a solution of zycosil and water in the following proportion by volume: (1:100), (1:200), (1:300) and (1:400) for 30 minutes and dried under normal atmospheric temperature and pressure before curing commenced.

The result of the capillary test on bricks samples after 24 h showed that AULB and CSLB have (0.35 and 0.15) kg weight difference equivalent to (0.00599 and 0.00256) $kg/m^2/min$ suction rate while the ISLB have 0.05 kg weight difference equivalent to 0.000855 $kg/m^2/min$ suction rate. The result of the erosion test for brick durability ranked between very firm for ISLB of 1:100, 1:200 and 1:300 Zycosil Water Solution (ZWS), firm for ISLB of 1:400 ZWS; firm for CSLB and loose for AULB. The abrasion test result showed that the ISLB has an abrasion value of (1, 2, 2 and 2) % while the CSLB and AULB have (3 and 12) % abrasion value. The densities of ISLB are (1933.50, 1921.18, 1916.26 and 1908.87) kgm^{-3} at 28 days while the density of CSLB and AULB were (1926.11 and 1800.49) kgm^{-3}. Density results conform to the minimum specification requirement for lateritic bricks of bulk density of 1810 kgm^{-3} as recommended by the Nigeria Building and Road Research Institute (NBRRI). Compressive strengths for the ISLB are (3.16, 3.10, 3.07 and 3.08) Nmm^{-2} at 28 days while the compressive strength test for CSLB and AULB stood at (3.15 and 2.41) Nm^{-2} which conforms to NBRRI recommended value of compressive strength ranges of (3 to 3.5) Nmm^{-2} at 5% stabilization level. It was concluded that the mechanical properties of improved stabilized lateritic brick are better than CSLB and AULB in terms of capillary rise, erosion, abrasion, density, and compressive strength.

The use of clay materials for the production of emulsion paints was investigated by Raheem and Olowu (2013). Two types of clay: White tinged with Purple and Smooth clay (WSP) and Grey Brown and Coarse clay (GBC), were used for the production of Emulsion Clay Paints (ECP). Conventional Chemical pigmented Paint (CP) was also produced as a control. Atomic Absorption Spectroscopy, (AAS) was used to determine the chemical composition of the clay and the concentration of heavy metals in the paints produced. Total organic content (TOC) and quality control tests were also carried out on the paints. The results of the analysis of the two clay types showed that they contained (45.26 and 47.370) % of silicon oxide and (38.26 and 35.72) % of aluminum oxide respectively. ECP has TOC values of (0.34-0.52) % while CP has TOC values of (0.29-0.31). The cost per litre of CP was (₦262.17) while that of ECP was (₦111.64), which is about 50% lesser. Clay paints are also safer to use than conventional chemical paints.

Titanium dioxide (TiO_2) is an inorganic, synthetic pigment used in paint to protect the substrate from the harmful effects of ultraviolet light. However, its use is limited since it causes flu-like symptoms, respiratory problems and skin irritation. Calcium carbonate ($CaCO_3$) is a chemical commonly used as an extender pigment in cement to provide bulkiness at a relatively low cost. Because of the problem associated with TiO_2, it is importance to regulate and optimize the use of TiO_2 relative to $CaCO_3$ and assess its influence on the physico-mechanical properties of emulsion paints. Raheem *et al.* (2019) assessed the influence and threshold ratios of TiO_2 and $CaCO_3$ as pigments on the Physico-Mechanical Properties of Emulsion Paint. Nine paint specimens were formulated using 0-80 g per litre of TiO_2 and 120-200 g of $CaCO_3$, at 10 g intervals. The following tests were performed on them: specific gravity, viscosity, pH, surface drying time, hard drying time, wash-ability/adhesion and opacity tests, in accordance to Nigerian Industrial Standard (NIS) 278: 1990. The result shows that all samples met specifications of 10 poise maximum, 5%, 7.5-9.0, 20 minutes, 2 h, and 201 minimum, for viscosity, specific gravity, pH, surface drying time, hard drying time and wash-ability/adhesion properties, respectively. It was concluded that TiO_2 has no negative effect on the other physio-mechanical properties except the opacity of the paint and that ratio 30:170 (TiO_2: $CaCO_3$) is considered the threshold value for the paint production.

The relatively high cost of man-made imported fibres like, glass, steel and plastics used in cement-based composites as reinforcement calls for investigation into the use of locally available natural fibre as a substitute. Fanpalm is a prospective reinforcing material in structural elements. Fanpalm is locally available and has been studied as a suitable alternative to steel reinforcement which is usually imported and expensive. The need for the durability of the fanpalm under varying exposure conditions is the concern of Raheem and Audu (2013). The ultimate tensile strength of fanpalm was determined under various exposure conditions to evaluate its possible usage, both on a short-term and long-term basis. Fanpalm specimens were cut, shaped and coated with various protective agents (sodium sulphate, magnesium sulphate, hydroxylamine, epoxy, and sulphur) and then cured in alkaline media (0.1 N sodium hydroxide solution) for 3, 7, 14, 28 and 56 days. A set of uncoated Fanpalm was subjected to the same curing conditions as the coated specimens to serve as the control. Tensile strength tests were carried out to evaluate the ultimate tensile stress at various ages for each of the exposure conditions. The results showed that epoxy-coated fanpalm specimens recorded the highest strength at 56 days of 80.83 Nmm^{-2} while magnesium sulphate-coated specimens had the lowest strength of 66.25 Nmm^{-2} during the same period. The uncoated specimens had an average strength of 65.00 Nmm^{-2} at 56 days in alkaline media. It could be said that the coating improves the tensile strength of fanpalm in alkaline media. It was concluded that fanpalm coated with epoxy could be used as a reinforcing material in concrete structures for short-term usage.

In a related study, the ultimate flexural strength of beams reinforced with fan palm under diverse exposure conditions was determined in order to evaluate its possible usage, both on a short- and long-term basis. Fanpalm specimens were cut, shaped to desired flexural reinforcements sizes and coated with water repellants (epoxy, sulphur and bitumen) and blocking agents (hydroxylamine, sodium sulphate magnesium sulphate) for 24 h. They were then used as reinforcements for concrete beams (75 x 100 x 500 mm) of 1:2:4 mix ratio and cured in alkaline media (0.1N sodium hydroxide solution). Two sets of uncoated fanpalm-reinforced beams (in alkaline solution and water) were used as control experiments. Flexural strength test was carried out on the specimen beams at ages 7, 14, 28, 56, 90, 180, 270, and 365 days. The results were subjected to ANOVA analysis using STATA software. The results at 365 days indicated that out of the beams reinforced with water-repellant agents, those reinforced with bitumen retained the ultimate flexural stress of 36.98 Nmm^{-2}. For the beams reinforced with fan palm coated with blocking agents, those reinforced with hydroxylamine recorded the ultimate flexural stress of 25.59 Nmm^{-2}. The ultimate flexural stress of beams reinforced with uncoated fan palm is 4.69 Nmm^{-2} and 18.07 Nmm^{-2} in alkaline and water media respectively. It was concluded that coating fanpalm reinforcements with bitumen (a water-repellant agent) improved the durability of fan palm-reinforced concrete beams.

Audu and Raheem (2017) studied the cracks and cracks' patterns with respect to the sustained loads for concrete slabs reinforced with fanpalm. Fanpalm logs were sliced, trimmed and smoothened to 10 × 10 mm and 12 × 12 mm sections using a band saw and grinding machine as shown in Figure 6. They are then used as reinforcements for concrete slabs of 1:2:4 mix and cured in water for 28 days. Flexural strength tests were carried out to evaluate the load causing the first visible crack and the load causing the full development of yield lines of fanpalm reinforcement concrete slabs. The theoretical yield loads were lower compared with the observed experimental yielding loads. The results revealed that the cracks increase with an increase in load. As the load systematically increased there was another sudden change in deflection at yield points. The highest percentage reinforcement 72% and 65% on y and x planes, respectively occurred on slab SLF2 with corresponding values of 16.20 kN and 29.35 kN at the first crack and yield point, respectively. It was concluded that Fanpalm could be used as the main reinforcement for structural elements that carries light loads. Also, Fanpalm could be used as distribution reinforcements while steel is used as main reinforcements in sections that have large spans and sections that carry heavy loads.

Figure 6: Samples of fanpalm reinforcement used.

Raheem and Audu (2019) carried out the theoretical and experimental investigation of the flexural strengths, deflection characteristics and cracking behaviours of fanpalm/steel-reinforced two-bay concrete portal frames. Fanpalm reinforcements were prepared by slicing and smoothing the faces into rectangular shapes of size 10 mm x 10 mm (cross-sectional) and of lengths 1460 mm and 510 mm. These fanpalms were arranged as reinforcements in the beams and columns of the portal frames as shown in Figure 7. Steel reinforcements of 8 mm diameter were arranged exactly like the arrangement of fanpalm reinforcements. The result showed linear load-deflection curves up to the first crack, thereafter, a nonlinear relationship between the load and deflection occurred irrespective of the reinforcement used. The fanpalm-reinforced portal frames exhibited larger deflections, increased crack numbers and crack widths compared with equivalent steel-reinforced ones. The number of cracks formed and the load-carrying capacities (flexural strength) of the frames up to the failure point increased with an increase in the percentage of reinforcements. Thus, fanpalm could be used in lintels as well as beams and columns in bungalow buildings.

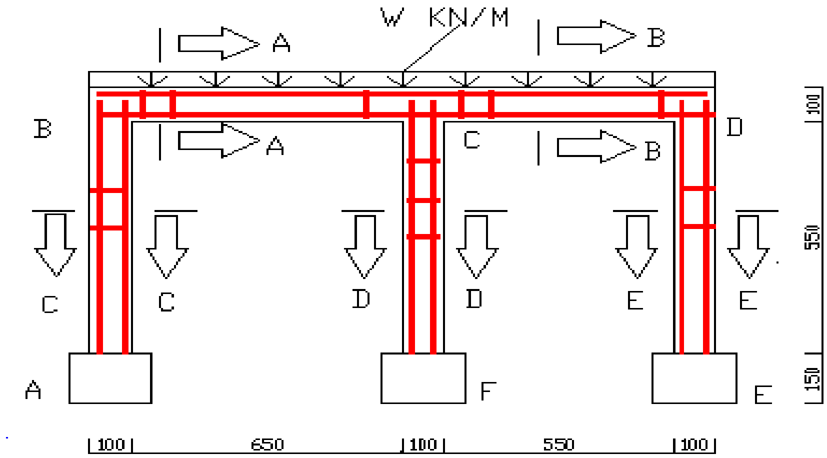


Figure 7: Theoretical two-bay fanpalm reinforced portal frame

4.0 APPLICATIONS OF SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCM)

Mr. Vice Chancellor sir, affordable housing had become elusive to the teaming population of the world due to the ever-increasing cost of construction materials. Concrete, being the most used building material has been seriously affected by the high cost of ingredients materials. With the little to non-acceptance of local building materials, attention was shifted to cement which is the most expensive and inevitable material in concrete. The search for alternative materials for cement in concrete led to the discovery of the potential of utilizing agricultural residues as partial replacement for cement in mortar and concrete. The use of these materials is an environmentally friendly method of disposal of large quantities of waste that would otherwise have become a nuisance. Extensive research had been carried out on the incorporation of agricultural residues as partial substitution for cement in mortar and concrete with findings showing their great potential (Genesan *et al.,* 2008; Adesanya and Raheem, 2009; 2010; Raheem and Adesanya, 2011; Raheem *et al.,* 2012c; Raheem *et al.,* 2017; Raheem and Ikotun, 2020; Orogbade *et al.,* 2021; Oyebisi *et al.*, 2023; Raheem and Anifowose, 2023; Oluremi *et al.*, 2023). Agricultural residues that had been studied for use as supplementary cementitious materials (SCM) in mortar and concrete are - Corn Cob Ash (CCA), Corn Stalk Ash (CSA); Corn Husk Ash (CHA), Rice Husk Ash (RHA); Sawdust Ash (SDA); Wood Ash (WA) and Neem Seed Husk Ash (NSHA).

4.1 Corn Cob Ash (CCA)

Corn or maize is an important cereal crop. According to Jarabo *et al.* (2013), it is the mostly produced cereal worldwide, surpassing wheat and rice. CCA is obtained from the burning of corn cob which is a waste product from corn or maize. Figure 8 shows a collection of corn cobs which was burnt at a calcining temperature of 650 ºC for 8 h (Adesanya and Raheem, 2009a). The chemical composition of CCA showed that it has high silica content (66.38%), indicating the potential for use as pozzolanic material. CCA has a combined percentage of $SiO_2 + Al_2O_3 + Fe_2O_3$ of 78.30% which is more than the 70% requirement by ASTM C 618 (1991) for a good pozzolan (Adesanya and Raheem, 2009a).

Figure 8: Corn cobs

CCA can either be mixed with cement on-site during concrete production or mixed with clinker during factory manufacturing of blended cement. When CCA was used as SCM, the concrete becomes less workable (stiff) as the CCA percentage increases meaning that more water is required to make the mixes more workable. A study by Adesanya and Raheem (2009b) indicated that for a

1:1½:3 concrete, the slump decreased from 35 mm to 12 mm as the percentage CCA substitution increased from 0 to 25% while the compacting factor decreased from 0.89 to 0.67. The high demand for water as the CCA content increases is due to the increased amount of silica in the mixture. This is typical of pozzolan cement concrete as the silica-lime reaction requires more water in addition to water required during the hydration of cement. In terms of compressive strength development, CCA-blended cement concrete has lower strength than that of plain concrete (the control) at early curing ages but improves significantly at later ages, and in fact, has a higher percentage gain in strength than the later. According to Adesanya and Raheem (2009b), an optimum value of 57.10 Nmm^{-2} at 8% CCA substitution was obtained for 1:1½:3 mix proportions.

The durability of CCA blended concrete using permeability and acid attack as criteria had also been investigated. The incorporation of CCA in concrete reduces its water absorption capacity. The decrease in permeability at lower CCA replacement may be attributed to the initial filling of voids by the CCA incorporated. At higher CCA replacement, however, there was an insufficient quantity of calcium hydroxide to react with the excess CCA thus creating pores in the mixture and thereby increasing the rate of water absorption. The optimum replacement level is between I0-15% (Adesanya and Raheem, 2010). As for acid attack, the addition of CCA up to 15% replacement level, led to a reduction in weight loss due to the reaction of concrete with HCl and H_2SO_4 acid water. The improvement was up to about 50% for HCl and 40% for H_2SO_4 acid water (Adesanya and Raheem, 2010).

The effect of CCA substitution for cement on the thermal conductivity of concrete had also been studied. Raheem and Adesanya (2011) reported that the incorporation of CCA in blended cement mortar decreased thermal conductivity (as shown in Figure 9) and improves the insulation properties of the material. This results in thermal comfort in buildings thereby reducing the cost of energy required for cooling, leading to energy conservation.

The incorporation of CCA in concrete resulted in lower workability and compressive strength, especially at early curing ages. A study was carried out to determine if the addition of different types of admixtures could solve this problem. Raheem *et al.* (2010) submitted that admixtures generally improve the workability of corn cob ash cement concrete. The greatest effect was caused by plasticizer which improves the flow properties of the mix by dispersing the cement particles and breaking up cement agglomerate. Also, the incorporation of admixtures in CCA cement concrete generally increases its compressive strength at all ages irrespective of the type used. As shown in Table 1, the use of Accelerator achieved greater strength at early ages while with Plasticizer, high strength was achieved at both early and later ages. With Water reducing and retarder, greater strength was achieved at later ages alone. Thus, in order to benefit maximally from the use of CCA concrete, the use of Plasticizer admixture is recommended.

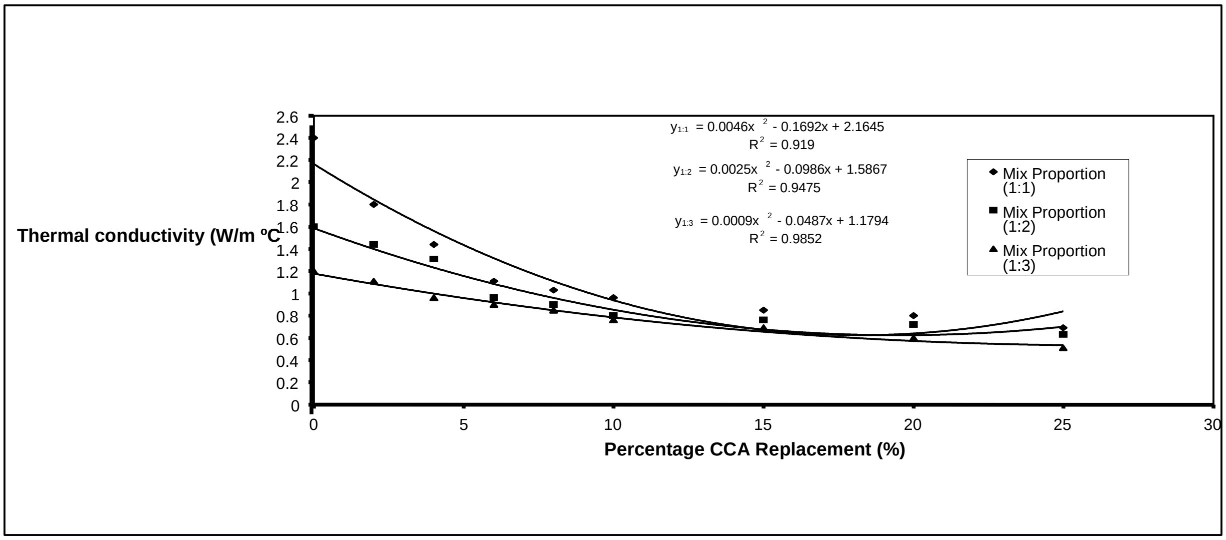


Figure 9: Effect of Percentage CCA Replacement and Mix Proportions on Thermal Conductivity of Blended Cement Mortar

Table 1. Summary of Compressive Strength of CCA Concrete with Admixtures

Class of Concrete	**1 Day (Nmm2)**	**3 Days (Nmm2)**	**7 Days (Nmm2)**	**14 Days (Nmm2)**	**28 Days (Nmm2)**
Concrete Cube without Admixture	10.42	12.71	15.30	21.85	29.82

Concrete Cube with Accelerator	13.19	15.40	17.33	24.89	32.80
Concrete Cube with Plasticizer	15.31	17.42	19.56	27.84	38.51
Concrete Cube with Water reducing and Retarder	12.07	15.29	17.88	25.78	34.09

4.2 Corn *Husk Ash (CHA)*

Corn husk is the leafy ear of corn that covers the maize. It is obtained as a waste product from corn consumption. Figure 10 shows the corn husk as it is being removed from the corn. Corn or maize is a widely grown cereal crop in sub-Saharan tropical Africa (Olakojo and Iken 2001). Corn Husk Ash (CHA) was obtained by burning corn husk at calcining temperature of 600 ºC for about 7 h. Raheem *et al.* (2012) studied the characteristics of CHA-cement concrete. The chemical composition of CHA indicated that it has combined percentages of (SiO_2 +Al_2O_3 +Fe_2O_3) of 74.97% > 70% required for good pozzolanic material in accordance with the requirements in ASTM C 618 (1991). The CHA has slightly lower silica content with a SiO_2 of 65.23% when compared with that of CCA with a value of 66.38% (Adesanya and Raheem, 2009a).

Figure 10: Corn Husk

As presented in Figure 11, the compressive strength of CHA concrete generally increased with the curing period and decreased with increasing amount of CHA content. Only 5% CHA substitution is adequate to enjoy the maximum benefit of strength gain (Raheem *et al.*, 2012). However, since all the specimens meet the minimum strength of 6 Nmm^{-2} after 28 days of curing recommended by BS 5224: 1976 for masonry cement, CHA concrete could be used for general concrete works where strength is of less importance such as in mass concrete, floor screed and mortar.

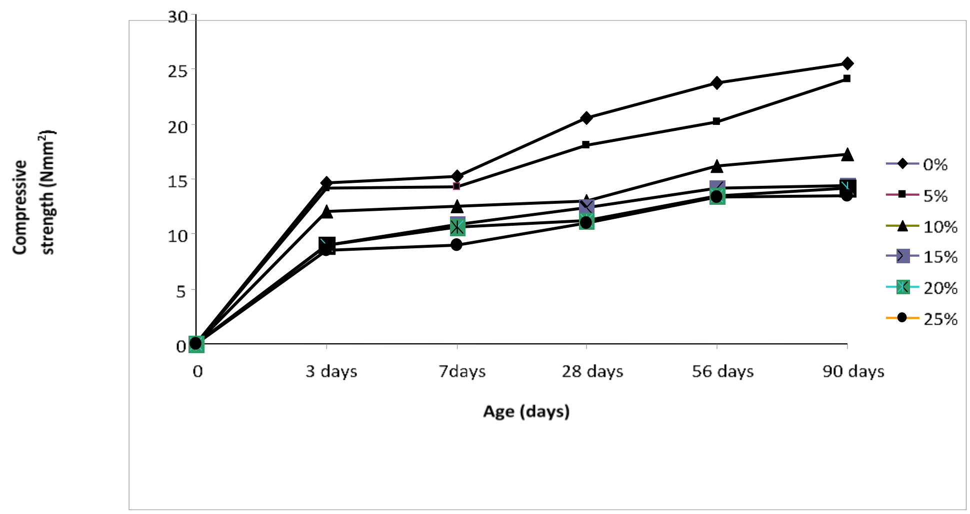


Figure 11: Effect of CHA replacement on the compressive strength of concrete

4.3 Corn Stalk Ash (CSA)

Corn stalk is a waste product obtained from maize after harvesting dried corn cubs from the stand (See Figure 12). CSA is obtained by burning corn stalks at a calcining temperature of 600 ºC for 7 h. In terms of chemical composition, CSA has combined percentages of silica, alumina and iron oxide of 71.86% which is more than the 70% requirement in ASTM C 618 (2005) for good pozzolanic material. The silica content of CSA (64.26%) is slightly lower than that of CCA with a value of 66.38% (Adesanya and Raheem, 2009a) and CHA with a value of 65.23% (Raheem *et al.*, 2012). The specific gravity of CSA is 2.19 which is lesser than that of cement which is 3.1.

CSA was used as a partial replacement for cement in the production of interlocking paving stones (see Figure 13) and it was observed that the compressive strength of the paving stones generally increased with curing age but decreased with increasing amount of CSA (Raheem *et al.*, 2017a). Interlocking paving stones with 10% CSA replacement and cured for 28 days minimum was recommended for use.

Corn stalk Corn Stalk Ash (CSA)

Figure 12: Dried Corn Stalk and it's Ash (Raheem *et al.*, 2017a)

Figure 13: CSA Interlocking Paving Stones

4.4 Rice Husk Ash (RHA)

Rice husk is a waste product obtained from rice production. The husk is removed from the rice during harvesting on farm. According to Khan *et al.* (2012), during milling, about 78% of weight is received as rice while about 22% of rice husk is produced. Rice husk is predominant in East and South Asia as a result of the favourable environmental condition in the area for rice production (Sargin *et al.*, 2013). Rice Husk Ash (RHA) is the by-product obtained after burning rice husk. Controlled burning of rice husk at about 700 ºC incinerating temperature transforms the silica content in RHA into amorphous phase which makes it more reactive. Several researchers had worked on the chemical composition of RHA and Table 2 indicated their findings. It could be observed from the table that SiO_2 is the predominant content in RHA with values ranging from 82.14 to 91.15%. The high silica content and its fineness which is greater than that of cement makes it one of the widely used SCM.

Table 2: Chemical composition of RHA

References	Common Oxide Composition (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O
Raheem and Kareem (2017a)	82.14	1.34	1.27	1.21	0.14	1.96	2.09
Mohseni *et al.* (2016)	91.15	0.41	0.21	0.41	0.05	0.45	6.25
Chatveera and Lertwattanaruk (2014)	90.61	0.50	1.40	0.82	0.02	0.50	1.92
Khan et *al.* (2012)	89.50	0.40	2.86	0.30	-	0.25	-
Ganesan *et al.* (2008)	87.32	0.22	0.28	0.48	1.02	0.28	3.14

As determined by Ganesan *et al.* (2008) the Mean Grain Size (MGS), average Specific Surface Area (SSA), Bulk Density (BD), Specific Gravity (SG) and Loss on Ignition (LOI) of RHA are

3.80 µm, 36.47 m^2/g, 0.40 g/cm^3, 2.06 and 2.10%, respectively. The MGS, SSA, BD and SG are lower than those of Ordinary Portland Cement (OPC) which are 22.50 µm, 326 m^2/kg, 1.16 g/cm^3 and 3.10, respectively. Lower MGS and LOI usually contribute to an increase in the compressive strength of pozzolan concrete.

Raheem and Kareem (2017a) carried out the optimization of the production of Rice Husk Ash (RHA) blended cement in a cement factory. Fourteen (14) experimental runs of RHA-blended cements were generated using a three-factor D-optimal design (RHA, Ordinary Portland Cement (OPC) clinker and gypsum). Design-Expert 6.0.8 was used to optimize the RHA-blended cement content. The results obtained indicated that the optimum mixture components for the production of RHA-blended cement were 12.45% RHA, 83.44% OPC-clinker and 4.11% gypsum. The D-optimal design was effective in enhancing the properties of RHA blended cement.

The chemical composition and physical characteristics of the RHA blended cement were examined by Raheem and Kareem (2017b). The RHA blended cement was produced by replacing 5, 7, 11.25, 15, 20.25 and 25% by weight of Ordinary Portland Cement (OPC) clinker with RHA. The cement without RHA serves as the control. The chemical compositions of RHA, OPC-clinker and the blended cements were determined using X-ray fluorescence analyzer. The incorporation of RHA led to an increase in the composition of SiO_2 and a reduction in that of CaO. An increase in RHA content showed a decrease in compressive strength at early ages but slightly increased at a later age (90 days). The blended cement produced with lower levels of RHA replacement conforms to standard specifications specified in BS EN 197-1:2000, NIS 439:2000 and ASTM C 150-02. The minimum Strength Activated Index (SAI) of 75% at the age of 28 days of curing as specified by ASTM C 618 was satisfied by RHA replacement of up to 15%. It was concluded that blended cement with the maximum of 15% RHA content is suitable for structural purposes.

Khan *et al.* (2012) performed X-ray diffraction analysis on RHA using XRD Diffractometer, Siemens D500 with K radiations. The result as indicated in Figure 14 showed a hump, indicating that it is amorphous and peaks of SiO_2 were observed showing that it is also crystalline. Thus, RHA exists in both amorphous and crystalline forms. The morphological features of RHA were also determined using scanning electron microscopic analysis. The result as shown in Figure 15 indicated that RHA consisted of irregular shapes with micro spores. The irregular shapes of RHA particles assisted in its filling effect capacity.

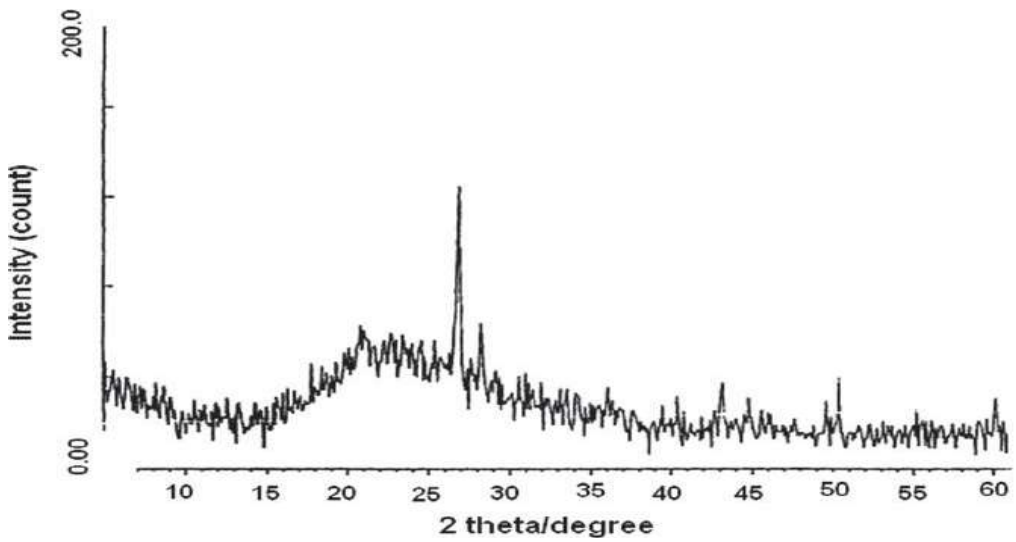


Figure 14: XRD pattern of rapidly cooled RHA (Khan et al., 2012)

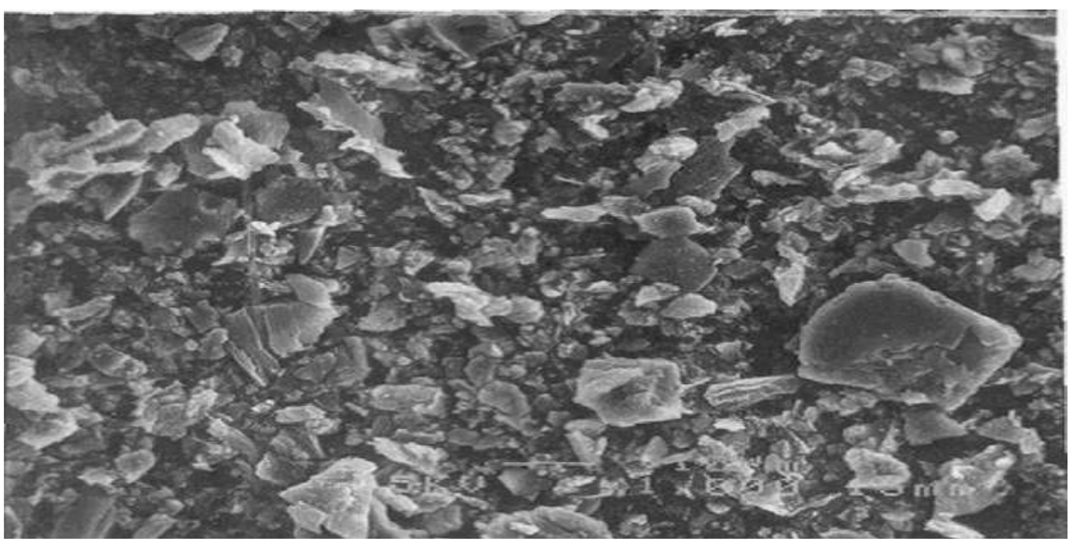


Figure 15: Scanning electron micrograph of RHA (Khan *et al.*, 2012)

The water permeability property of RHA blended cement concrete was studied by Genesan *et al.* (2008). It was reported that at 28 days, the percentage of water absorbed increased with RHA content up to 35%. At 90 days, however, the percentage of water absorbed decreased with an increase in RHA content up to 25%. This indicated that prolonged curing of RHA blended cement concrete led to a reduction of permeable voids. Chloride permeability was also reduced by partial replacement of OPC with RHA up to 30%. This is due to the low-value LOI of RHA which contributed to the reduction in the electrical charge passed.

Raheem *et al.* (2021d) examined the thermal properties of Rice Husk Ash-blended Palm Kernel Shell Concrete (RHA-blended PKSC). Three control concrete mixes with mix ratios of 1:1½:3, 1:2:4 and 1:3:6 using water-to-cement (w/c) ratios of 0.5, 0.6 and 0.7, respectively were made with cement, river sand and granite. For each mixing ratio with the respective w/c ratio, five concrete mixes containing RHA fixed at 15% replacement for cement and PKS at 20, 40, 60, 80 and 100% replacement for crushed granite were produced. The oven-dry density, compressive strength and thermal properties (thermal conductivity, thermal diffusivity, volumetric heat capacity and thermal resistivity) were determined. Figure 16 shows the experimental setup for the determination of thermal properties using the KD2 Pro-thermal properties analyzer.

The results showed that the oven-dry density and compressive strength of concrete declined with increasing PKS content. Nevertheless, the compressive strength increased with curing age and the gain in strength of RHA-blended PKSC was higher than the control at later ages. The thermal conductivity and diffusivity decreased with increasing PKS contents but increase with curing age while volumetric heat capacity and thermal resistivity increased as PKS content increased but decreased with curing age. In addition, concrete with a 1:3:6 mix ratio exhibited the lowest thermal conductivity and diffusivity but higher volumetric heat capacity and thermal resistivity than those with 1:1½:3, 1:2:4 mix ratios. RHA-blended PKSC with 40% PKS and 15% RHA for a 1:1½:3 mix ratio attained the compressive strength and thermal conductivity values recommended for lightweight aggregate concrete which is suitable for structural and insulation purposes. It was concluded that the combined use of PKS and RHA as raw materials in concrete is effective in improving concrete's thermal and insulation properties.

Figure 16: Experimental set-up for determination of thermal properties using KD2 Pro-thermal properties analyzer

The effects of ash fineness (75, 150 and 300 µm) and contents (10, 20, 30, 40 and 50%) on the consistency and Setting Times (ST) of RHA blended cement were examined (Raheem and Anifowose, 2023). RHA was characterized through X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). Cement pastes were prepared in accordance with British standards (BS EN 196–3) to determine the consistency and ST of RHA blended cement. The XRF results revealed silica as the major compound in the RHA (72.6%) which confirms it as a good pozzolanic material suitable for use as a supplement in cement. The XRD and SEM micrograph revealed the siliceous nature of the RHA due to the presence of quartz in the ash (this suggests the usefulness of the RHA as binding material). The consistency of the RHA blended cement increased with increments in the ash fineness (75 to 300 µm) and content (10 to 50%). This led to a high amount of water to produce a paste. The initial and final ST of the RHA blended cement paste also increased with an increase in RHA content and fineness. It was concluded that the finer the RHA blended cement the earlier the ST.

2.5 Sawdust Ash (SDA)

Sawdust is a waste material obtained from the timber industry. It is produced from the sawing of timber into planks at sawmills which are in countries that have thick forests with abundant trees. As production progresses, sawdust becomes continuously heaped up thereby causing nuisance to the environment (see Figure 17).

Figure 17: Sawdust produced from cutting logs of timber into planks

Sawdust ash (SDA) is produced by burning sawdust at a calcining temperature of 650 ºC for about 8 h. SDA is also known as wood waste ash (WWA) and sawdust waste incineration fly ash (SWIFA). The chemical composition of SDA had been widely studied. Table 3 showed the elemental composition of SDA as obtained by various researchers.

Table 3: Summary of the chemical composition of SDA

References	Elemental Oxide Composition (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	LOI
Elinwa and Mahmood (2002)	67.20	4.09	2.26	9.98	5.80	-	0.08	4.67
Udoeyo and Dashibil (2002)	78.92	0.89	0.85	0.58	0.96	-	0.43	8.40
Elinwa *et al.* (2008)	67.20	4.10	2.30	10.00	5.80	0.10	0.10	-
Raheem *et al.* (2012)	65.75	5.23	2.09	9.62	4.09	2.43	0.06	4.30
Chowdhury *et al.* (2015b)	65.30	4.25	2.24	9.98	5.32	1.90	2.60	4.67
Raheem and Ige (2019)	69.29	5.22	2.03	10.07	5.48	0.86	9.68	3.64

It could be observed from Table 3 that SiO_2 is the main elemental oxide in SDA with composition ranging from 65.30% to 78.92%. The combined SiO_2 + Al_2O_3 + Fe_2O_3 of more than 70% as stipulated by ASTM C 618 was satisfied by all the authors. Thus, SDA is a good pozzolanic material. The physical properties of SDA as obtained by Chowdhury (2015a) are specific gravity - 2.16, mean size – 170 µm and bulk density – 720 kg/m^3.

According to Raheem *et al.* (2012c), the workability of concrete reduces as the SDA percentage increases meaning that more water is required to make the mixes more workable. The high demand for water as SDA increases is due to the increased amount of silica in the mixture. This is typical of pozzolan cement concrete as the silica-lime reaction requires more water in addition to the water needed during the hydration of cement.

The compressive strength of SDA concrete was investigated by Elinwa and Mahmood (2002). The results indicated that the compressive strength decreases as the percentage of SDA in the mix is increased. This result was corroborated by Raheem *et al.* (2012c) who extended the curing period beyond the 28 days studied by Elinwa and Mahmood (2002) and discovered that prolonged curing is more beneficial to SDA concrete. The study found that higher percentage increases in strength were recorded beyond 28 days. The significant increase in strength was due to the pozzolanic reaction of SDA and the continuous hydration of cement.

Raheem and Ige (2019) studied the flexural strength of SDA mortar. The results as shown in Figure 18 indicated that the flexural strength of mortar increased with age and decreased with an increase in SDA content. However, the rate of decrease diminished with the increasing age of curing. At 56 days, the percentage increase with respect to the 28 days flexural strength for control was 13.5%, while it was 42.6, 44.0, 32.7, 28.6 and 10.3% for 5, 10, 15, 20 and 25% SDA replacements, respectively. The percentage increase in flexural strength was found to be increasing as the SDA percentage replacement increases from 0 to 15% SDA and then reduced to 20–25% SDA replacement. Thus, the optimum percentage replacement was 15%.

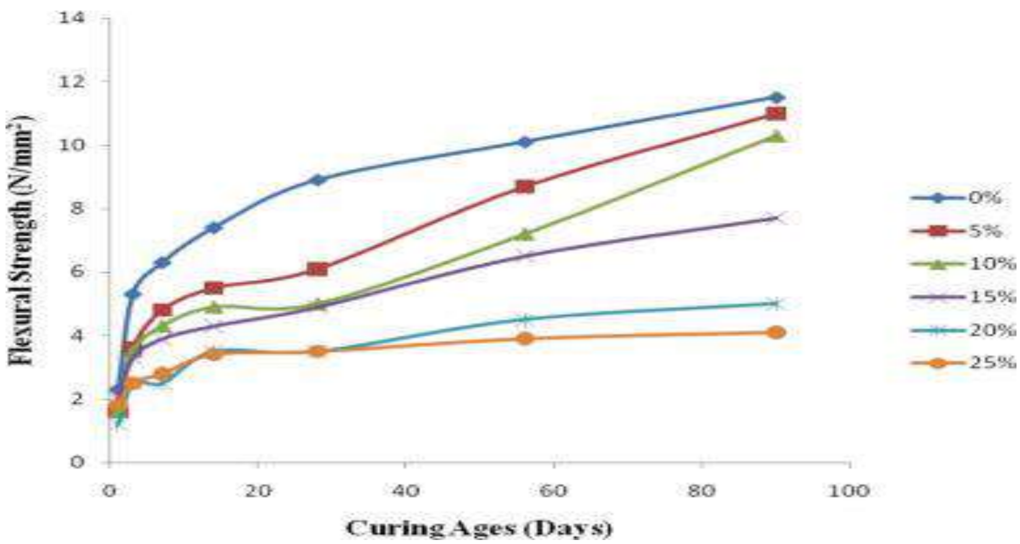


Figure 18: Flexural strength of SDA blended cement mortar

The splitting tensile strength of SDA blended cement concrete and X-Ray Diffraction (XRD) analysis of SDA sample was performed by Chowdhury *et al.* (2015a). The result showed that splitting tensile strength decreased with increasing SDA content. However, the reduction was less pronounced when compared with that of the compressive strength of SDA concrete. The reduction was attributed to the filler activity of SDA particles in the concrete (Udoeyo and Dashibil, 2002).

The XRD pattern of the SDA sample as shown in Figure 19 indicated a hump as well as peaks of SiO_2. The hump showed that SDA is amorphous while the peaks of SiO_2 represented crystalline nature. Thus, SDA has both amorphous and crystalline forms of SiO_2. This further confirmed that SDA is a good pozzolanic material for replacing cement.

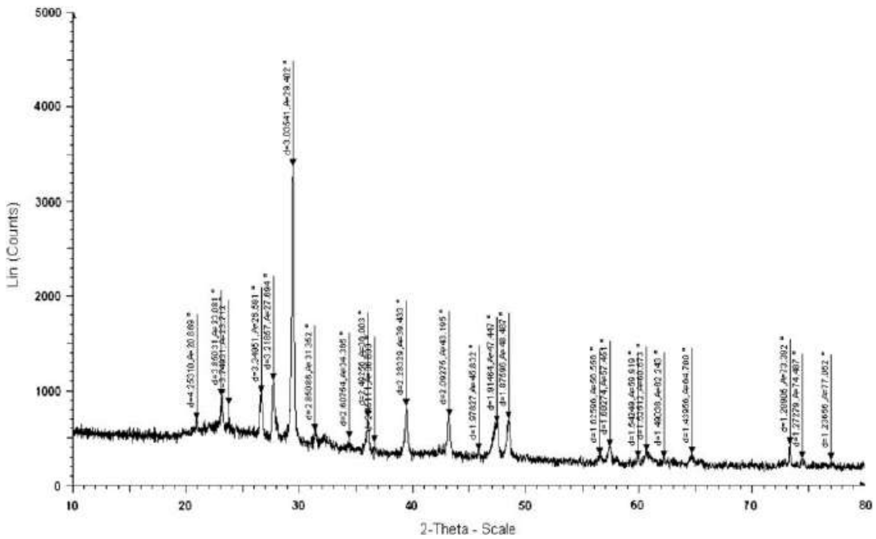


Figure 19: XRD of SDA (Chowdbury *et al.*, 2015a)

4.6 Wood Ash (WA)

Wood ash (WA) is quite similar to SDA and in fact, both are used interchangeably. Both are from wood, only the method of obtaining them differs. WA is obtained by burning timber while SDA is obtained by incinerating the sawdust produced as timber is sawn into planks at sawmills. The main sources of WA are from everyday cooking involving wood or charcoal and from local bread bakeries (see Figure 20).

(a) Firewood (b) Charcoal (c) Local bread bakery

Figure 20: Sources of Wood Ash

The chemical composition of WA is like that of SDA. However, the silica content is slightly lower ranging between 61.18 and 65.88% (Raheem and Adenuga, 2013; Raheem and Orogbade, 2018). In a study on the chemical and physical characterises of blended cements produced by incorporating wood ashes from three types of softwood, Orogbade and Raheem (2018) reported that the silica content of softwood ashes ranges from 62.05 to 62.10%. Also, while considering three different types of hardwoods, Raheem and Orogbade (2018) informed that the silica content is between 64.00 and 65.88%. Thus, hardwoods have higher silica content than softwoods.

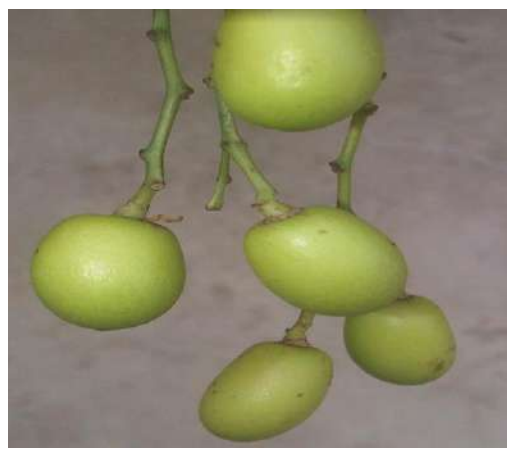
Raheem and Orogbade (2018) considered the characteristics of blended cement produced with ashes from three types of hardwood namely: -*Tectonagrandis* (Gedu) [TGA], *Cassia siamea* (Kasia) [CSA] and *Vitellaria paradoxa* (Emi) [VPA]. Findings from the study indicated that all the hardwood ashes (TGA, CSA and VPA) are suitable materials for use as pozzolan. Also, TGA, CSA and VPA blended cement have lower setting times than the control (without ash) and satisfied ASTM C 150:1994 and NIS 439:2000 requirements for up to 20% replacement of ash. They are applicable where low heat of hydration is required like in dam construction.

4.7 Neem Seed Husk Ash (NSHA)

NSHA is produced by burning Neem seed husk which comes from the Neem tree (*Azadirachta indica*). Neem Seed Husk is a residue that is obtained during the industrial processing of Neem Seed to extract oil and produce fertilizer. The Neem or Margosa tree and its seed as shown in

Figure 21 is a tropical evergreen tree native to India and is also found in other South - Eastern countries. Neem or Margosa is a botanical cousin of mahogany. It belongs to the family Meliaceae (Neem Foundations, 2007). Neem tree is readily available in most temperate environments and is locally called “dongoyaro” in one of the Nigeria dialects, but it is predominantly present in the northern part of Nigeria and some parts of the South-West.

The chemical composition of NSHA as studied by Raheem and Ibiwoye (2018) is presented in Table 4. It could be observed from the table that the main constituents of NSHA are Silica (SiO_2); Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3). The combined percentage of SiO_2, Al_2O_3 and Fe_2O_3 is 75.34 % which is above the 70% required by ASTM C 618 for a material to be suitable for use as a pozzolan. This result is similar to those of other pozzolans such as corn cob ash (CCA) and Rice husk ash (RHA). Thus, NSHA can be categorised as a Class F pozzolan suitable for producing good concrete.



a: Neem Tree b: Neem Fruit

(pendent: neem tree flowers)

c: Neem Seed

d: Neem Husk

Figure 21: Neem Tree, Pod, Seed, and Husk

Table 4- Chemical Composition of Neem Seed Husk Ash (NSHA)

Constituents	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Average (%)
SiO_2	69.14	69.13	69.16	69.14
Al_2O_3	2.94	2.96	2.94	2.95
Fe_2O_3	3.25	3.24	3.27	3.25
CaO	2.75	2.77	2.76	2.76
MgO	0.54	0.56	0.55	0.55
SO_3	0.42	0.43	0.41	0.42
Na_2O	0.15	0.14	0.17	0.15
K_2O	15.01	15.02	15.04	15.02

TiO_2	0.24	0.26	0.24	0.25
P_2O_5	1.01	1.01	1.01	1.01
Mn_2O_3	0.04	0.04	0.05	0.04
$SiO_2+Al_2O_3+Fe_2O_3$	**75.33**	**75.33**	**75.37**	**75.34**

Raheem and Ibiwoye (2018) also investigated the compressive strength of NSHA concrete. The results as presented in Figure 22 indicated that compressive strength generally increased with an increase in curing age and decreased as the percentage content of NSHA increases. Due to the onsite mixing of the NSHA with OPC at the point of concrete production, only 5% substitution by weight is adequate for the maximum benefit of strength gain.

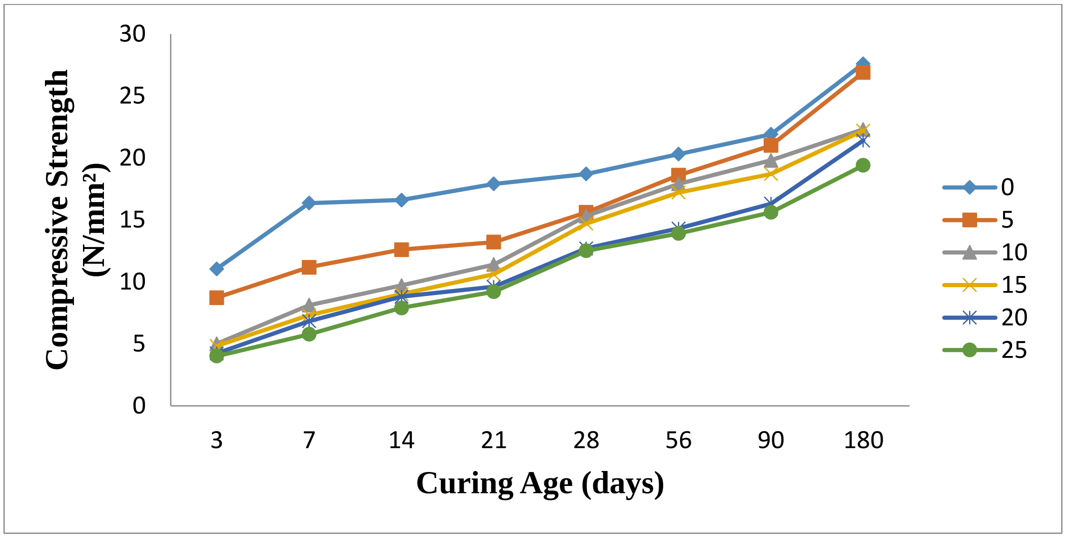


Figure 22: Effect of Curing Age on Compressive Strength of Concrete

In order to accommodate more NSHA, Raheem and Ibiwoye (2019) investigated the characteristics of NSHA blended cement produced in the factory. Blended cement was produced by intergrinding 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50% by weight of NSHA with ordinary Portland cement (OPC) clinker and gypsum. The blended cements produced were analyzed for chemical composition (SiO_2, Al_2O_3, Fe_2O_3, CaO) and physical properties (fineness, initial and final setting time, heat of hydration). The percentage of SiO_2, Al_2O_3, Fe_2O_3 and CaO for blended cement with 5% - 50% ash replacements ranged from 20.21 – 20.81, 5.41 – 3.86, 3.21 – 1.92 and 62. 76 – 42.48, respectively. The corresponding fineness, initial and final setting time; and heat of hydration for the blended cement ranged from 230 – 740 m^2/kg, 45 – 72 min, 135 – 235 min, and 34 – 49 cal/g, respectively. It was concluded that factory-produced NSHA–blended cement is suitable as it satisfied the minimum requirements as provided in available codes. NSHA blended cement has higher setting times than OPC cement, hence, it is most applicable where a low rate of heat development is required such as in mass concrete work and dam construction.

5.0 IMPROVEMENTS IN THE CHARACTERISTICS OF CONCRETE WITH SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCM)

Pozzolan concrete incorporating SCMs has been shown to exhibit low workability and reduced early strength development, especially with high content of SCM (>10%). These negative effects of the partial replacement of cement with SCM's need to be tackled to maintain the integrity of the concrete. One way that was considered is the addition of nanoparticles to pozzolan concrete.

Nanoparticles are highly reactive materials that have been used to improve the structural efficiency, durability and strength of concrete. As reported by Stenfanidou and Papayianni (2012), nanoparticles act as fillers in empty spaces and as crystallization centers of hydrated products, thereby increasing the rate of hydration and strength development. Nanomaterials that are commonly used in concrete and mortar are nano-SiO_2, nano-TiO_2, nano-Al_2O_3, nano-Fe_2O_3, nano-ZnO and carbon nano-tubes (Heikal, 2013; Sharobim and Mohammedin, 2013; Mohamed, 2016; Ren *et al.,* 2018).

Raheem and Ikotun (2019) investigated the influence of nano silica on the workability and compressive strength of wood ash cement concrete. Wood ash was obtained as a waste product from Ladoke Akintola University of Technology (LAUTECH) bread bakery, Ogbomoso. Biological synthesis of nanosilica using kola Pod extract and silica precursor (1:5) was conducted at Nanotechnology Research Group Laboratory at LAUTECH. The chemical composition, specific gravity and particle size distribution of wood ash, fine and coarse aggregate used were determined. Concrete with 10% wood ash replacement for cement was produced using a 1:2:4 mix proportion and water to binder ratio of 0.5. Nanosilica was added at 0.5, 1.0, 1.5 and 2.0% levels. Concrete with no wood ash and nanosilica served as the control. The results showed that concrete workability was enhanced with the introduction of nanosilica. The compressive strength also increased with the addition of nanosilica. Maximum compressive strength of 27.53 MPa was achieved at 90 days with 1.5% nanosilica addition. It was concluded that nanosilica enhanced workability and improved both early and later strength development in wood ash concrete with 1.5% as the optimum addition.

Ikotun and Raheem (2021) considered the influence of green-synthesised nano-TiO_2 (NT) on the characteristics of wood ash (WA) cement mortar. Mortar specimens were prepared by partial replacement of cement with WA (10% by weight) and the addition of 1, 2 and 3% NT by weight of the binder. The properties evaluated are the setting time of the binder and flexural and compressive strength with water absorption of the mortar. The results indicated that the addition of 1 and 2% NT reduced the setting times of WA cement paste. As indicated in Figure 23, the compressive strength of WA cement mortar was higher with the incorporation of up to 2% NT. Thus, it was concluded that the incorporation of NT in WA-cement mortar improved its workability and strength characteristics.

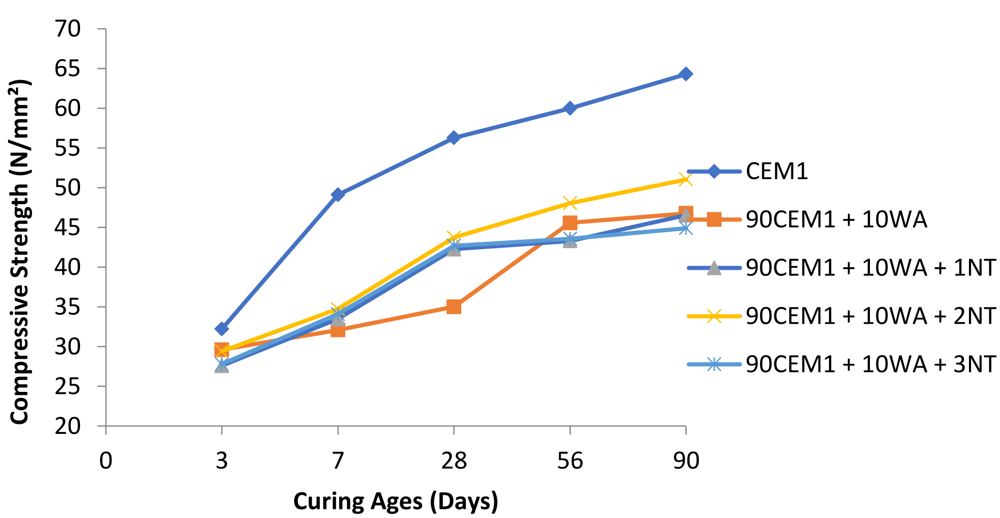


Figure 23. Effect of nano-TiO_2 on compressive strength of wood ash cement mortar

Raheem *et al.* (2021e) examined the properties of factory-produced blended cement using metakaolin from three different sources and considered the effects of nanosilica on the blended cement mortar. Kaolin clay sourced from Ijero, Ikere, and Isan in Ekiti states was calcined at 700 ˚C for 1 h and thereafter, characterized using X-Ray Fluorescence Analyser (XRF) and X-Ray Diffraction Analysis (XRD). Ordinary Portland Cement (OPC) clinker and 10% metakaolin were used to produce blended cement. Liquid nanosilica was synthesized from cola pod extract and silica precursor in a ratio of 1:5. A cement and sand ratio of 1:3 and water/binder ratio of 0.5 was used to produce metakaolin blended cement mortar with the addition of nanosilica in varying percentages of 1, 2, 3, 4 and 5% by weight of the binder. The setting times and water demand of the blended cement mortar were determined. The results revealed that the setting times and water demand were observed to reduce as the percentage of nanosilica was increased up to a level of 4%. Also, the results of the XRF classified metakaolin as Class N pozzolan with the addition of SiO_2, Al_2O_3, and Fe_2O_3 greater than 70%.

Oluremi et al. (2023) examined the influence of Nano Silica (NS) on the early strength development of Corn Cob Ash (CCA) concrete. CCA was produced by the open burning of clean and dried corn cobs sourced from farms within Ogbomoso environs. NS was obtained from Nanotechnology Research Group Laboratory at Ladoke Akintola University of Technology. Concrete specimens of size 150 mm cubes were produced from the mixture of cement, crushed granite and sand, batched in a ratio of 1:2:4. A constant amount of 10% CCA by weight of cement was used for replacement of cement while 0.5, 1, 1.5 and 2% NS by weight of cement were added to the mixture to investigate the strength development in concrete. The results revealed that the incorporation of CCA as a partial replacement for ordinary Portland cement decreased the early development of compressive and tensile strengths of the concrete. However, the addition of NS up to 2% enhanced the strength development.

The effect of incorporating Synthesised Nanosilica (NS) on selected properties of wood ash (WA) cement mortar was studied by Ikotun and Raheem (2023). Cement paste samples were prepared for testing setting times of cement while mortar samples were prepared to investigate the flexural and compressive strength of mortar. The samples were prepared with 10% by weight of cement WA replacement for cement and 1, 2 and 3% by weight of binder addition of NS. A constant water-binder ratio of approximately 0.4 was maintained for cement pastes samples and 0.5 for mortar samples. The results indicated reduction in setting times of WA cement mortar with 1 and 2% NS. As obtained from Figure 24, an increase in flexural strength was observed for mortar samples with up to 2% NS addition. Similarly, the compressive strength increased with curing age and addition of NS up to 2%, beyond which it decreased (Figure 25). The mortar with 2% NS addition has higher strength than that of normal cement mortar. The increase in strength over that of normal cement mortar is due to the continuous pozzolanic reaction of the WA at longer curing ages. With the addition of NS, the increase is due to the packing effect of small-size NS that acted as fillers and the pozzolanic effect that combines silica in NS and WA with calcium hydroxide from cement to produce a strong hydrate of calcium silicate (C-S-H) bond.

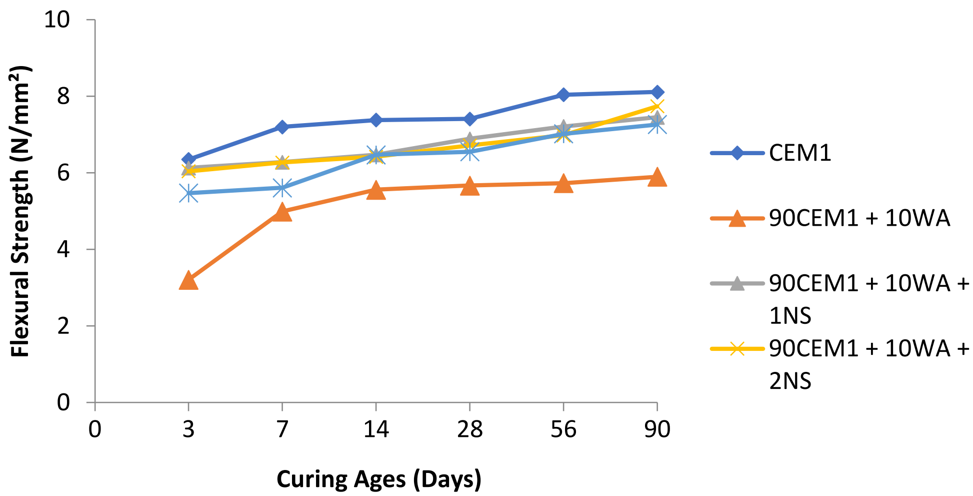


Figure 24: Flexural strength of wood ash cement mortar incorporating Synthesised Nanosilica

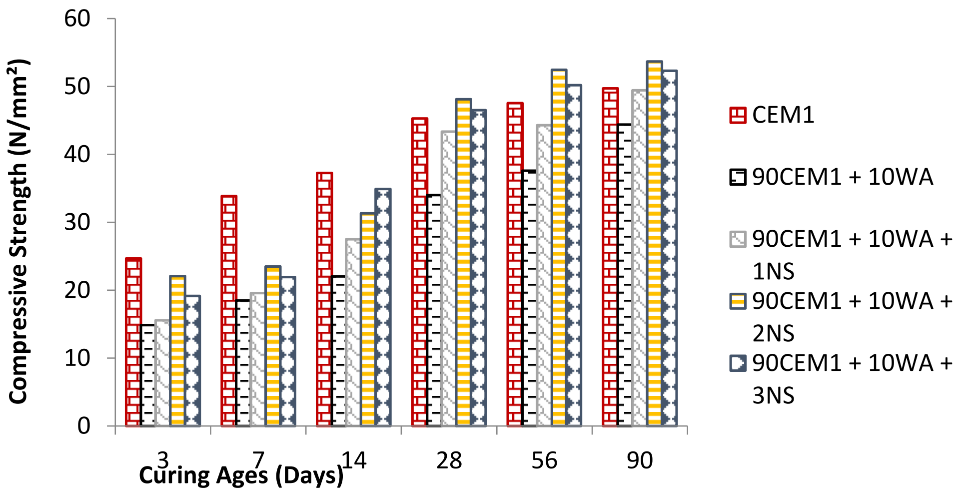


Figure 25. Compressive strength of wood ash cement mortar incorporating Synthesised Nanosilica

6.0 CURRENT RESEARCH ACTIVITIES

After a series of experimental studies on the various SCMs considered, we zeroed in on only two (2) of them for further study viz: Rice Husk Ash (RHA) and Wood Ash (WA). This is because it is only the two of them that are available in the required form as residue which do not need further processing. Also, they are available in large quantities as there are numerous rice mills and bread bakeries in the country.

Presently, we are working on the use of RHA and WA in sandcrete blocks production. We are continuing our investigation on the application of nanoparticles in improving the performance of pozzolan concrete through the incorporation of other types of nanomaterials such as nano-Al_2O_3, nano-Fe_2O_3, nano-ZnO and carbon nano-tubes. The possibility of accommodating more volumes of RHA and WA without adversely affecting the properties of the mortar and concrete is our major focus.

The application of Super Absorbent Polymer in improving the characteristics of Wood Ash Blended Cement is also under study. We are also considering - Effects of Calcium Nitrate Addition on the Characteristics of RHA and WA Blended Cement Concrete. Durability studies and thermal performance of mortar and concrete incorporating RHA and WA are our next targets in order to ensure the long-term utilization of these materials.

In order to determine what constitutes affordable housing, a Study on Affordable Housing made with Laterite Interlocking Bricks (LIB) and Rice Hush Ash (RHA) Blended Cement is being considered. Practical construction of a model unit of building would be made and its cost compared with a similar prototype made with sandcrete blocks and OPC. This is with a view to encouraging the utilization of LIB and RHA blended cement in the development of mass housing estates.

7.0 ACTIVITIES FOR PROMOTING THE USE OF INNOVATIVE CONSTRUCTION MATERIALS

Mr. Vice Chancellor Sir, I have been engaging in various activities to promote the use of Innovative Construction Materials (ICM) within and outside Nigeria. In 2018, I was selected for the Visiting Researcher Support Programme (VRSP) of the University of South Africa (UNISA). I got an opportunity to do research in collaboration with my host - Prof. B.D. Ikotun at the Department of Civil and Chemical Engineering for a whole year. It was during this period that I consolidated my research into the application of nanomaterials in Wood Ash (WA) concrete. Nano Silica and Nano Titanium were explored for improvement of the characteristics of WA concrete. The efforts yielded positive results as five (5) journal articles were published from it in reputable international journals with high impact factors.

In the year 2019, I sponsored myself to the 18th International Conference on Non-Conventional Materials and Technologies with the theme "Construction Materials & Technologies for Sustainability" (18th NOCMAT 2019) held from 24-26th July 2019 at the University of Nairobi Towers, Nairobi, Kenya. I presented a paper with the title – "Chemical Composition and Selected Physical Characteristics of Neem Seed Husk Ash Blended Cement" to the admiration of the audience which comprised citizens from the United States, the United Kingdom, Asia, Europe, Australia and Africa. It was at the conference that all materials incorporating pozzolans and those different from the normal construction materials that are well known are termed: Non-

Conventional- Materials (NOCMAT). It was also at this conference that I started ruminating over the title of today's inaugural lecture.

I was invited as a Keynote Speaker at the International Conference on Addressing Societal Challenges through Innovative Engineering Research; organized by The Nigerian Society of Engineers, Yola Branch, held at American University of Nigeria, Yola, Nigeria, between 9 – 12th November 2020. I presented a paper with the title - Addressing Sustainable Housing Challenges through Innovative Materials Research. The keynote address examined the use of locally available and tested materials, in addressing the challenges of low-cost housing delivery for the teaming populace of the world. In order to construct a sustainable and affordable building, what is paramount is to survey the location of the structure and identify the readily available materials which can be suitably used either as supplementary cement replacement or fine and coarse aggregates in concrete or block production. The agricultural residue considered for use are CCA, CSA, SDA, WA, and NSHA for partial replacement of OPC; and Palm Kernel Shell (PKS), Coconut Shell and Periwinkle Shell as replacement for aggregates.

As part of my goal of promoting the use of ICM in concrete and mortar, the Cement and Concrete (CEMCON) Research Group was formed in the year 2021. It is a trans-campus and trans-border research group consisting of researchers within and outside Nigeria. The group provides a forum for researchers and academia to discuss the challenges, advanced techniques and new frontiers in the production, processing, analyses and testing of cement and concrete materials for sustainable development. The aim of the group is to engage in collaborative research on cement and concrete materials for the benefit of our nation and the world at large, and the dissemination of the research products through organised seminars, workshops and conferences. The group has been making waves since its inception.

Towards fulfilling one of her mandates, in November 2022, the CEMCON Group, LAUTECH, Ogbomoso in collaboration with Sustainable Green Concrete Research Group (SGCRG), University of South Africa (UNISA), South Africa organised the First International Conference on Advances in Cement and Concrete Research, (ICACCR 2022) between Tuesday, 15th to Friday 18th November 2022 at The Great Hall, LAUTECH, Ogbomoso, Nigeria. It was a Hybrid conference (Onsite and Virtual). A total of Seventy-Two (72) papers were accepted for presentation at the event. As I speak with you today, about 30 papers that meet the journal standard are being processed for publication in Materials Today Proceedings –a Scopus-indexed journal with high impact factor published by Elsevier. Preparation for the second edition of the conference - ICACCR 2023, is already in top gear.

PICTURES SPEAK

I participated as a speaker at the 4th Edition of the Ibadan International Housing and Construction Fair held between 24 and 25th August 2022; with the Theme: Rethinking the National Housing Policy to Bridge the Gap between Sustainability and Affordability. I presented a paper where I solicited the use of two alternative building materials viz:

i. Laterite Interlocking Blocks (LIB) and

ii. Supplementary Cementitious Materials (SCM).

LIB is produced from laterite and small quantity of cement (5-10% by weight) and can be used to replace the conventional sandcrete hollow blocks which are more expensive. Wood ash (WA) and Rice husk ash (RHA) were the SCM proposed for use as partial replacement for ordinary Portland cement. It was quite a successful fair with various housing estate developers and mortgage banks in attendance.

On the 24th of November 2022, I led the CEMCON group to a meeting with TINATH and their foreign partner at the Best Western Hotel, Oba Akenzual Cresent, Iyaganku, Ibadan. The discussions centered on the possibility of using some of our research findings in the Smart City housing estate development of the company. Further deliberations are ongoing.

It is also worth noting that some members of the CEMCON group led by Dr. S.O. Ajamu won a TETFund NRF grant award worth #18 M last year. We presented four concept notes for the year 2022 and one was successful. It was an achievement for us since that was the very first time we participated in the TETFund NRF concept note presentation. Glory be to God Almighty. More to come, Insha Allah. Aamiin.

8.0 CONCLUDING REMARKS

All said and done, the bottom line of our research is to make the construction of buildings affordable to the teaming populace of the world irrespective of their earnings, location and status. Since the cost of materials accounts for two-thirds of the total cost of building construction, adequate sourcing of local materials and incorporation of Supplementary Cementitious Materials (SCM) as partial replacement for the conventional and expensive Ordinary Portland Cement (OPC), would go a long way in reducing the cost of owning a building.

In order to construct a sustainable and affordable building, what is paramount is to survey the location of the structure and identify the readily available local materials which can be suitably used either as walling material or for supplementary cement replacement in concrete or block/brick production. The percentage replacement to adopt depends on the use of the building component (load-bearing or non-load bearing). For load-bearing elements, replacement beyond 20% is not advisable while for non-load-bearing components, up to 50% replacement is practicable. Also, the use of LIB as walling material is a better alternative to sandcrete blocks where laterite is readily available. These materials are affordable since they readily available in large quantities and a high percentage of them are actually waste products; thus, cost is minimal. They are reliable in that their strength and durability characteristics had been confirmed to be at per or even suppass those of conventional materials. Their sustainability emanated from the fact that they are obtained from renewable sources, with no fear of deplection and not contributing to environmental degradation.

Finally, with the application of technology to locally available alternative building materials, they metamorphosed into innovative materials and enable the culture of construction to be changed for the development of sustainable, reliable and affordable houses for the teaming population of the world.

9.0 RECOMMENDATIONS

Based on the findings from our various endeavours in the study of local and innovative construction materials, the following recommendations are put forward:

i. The research findings of most studies on new materials development have not gone beyond the researcher's desk in terms of implementation of the laudable results obtained due to lack of sponsorship from government or industries for mass production and marketing of the new product. There should be collaborations between researchers and industries to convert their findings into tangible products;

ii. In most institutions of learning in Nigeria, there are no adequate facilities for research. Where some elements of equipment are available (Courtesy of TETFund), they are either non-functional or below the specification required. It is recommended that end users must have a positive say in the procurement of equipment for their departments;

iii. Factory grinding of SCM's with cement clinker is preferred against on-site mixing in order to ensure uniform blending and allow higher quantities of the SCM's to be incorporated.

iv. Only local materials that are available within the project area should be considered to eliminate the additional cost of transportation to the point of need. Also, the cost of treatment should be minimal.

v. The percentage replacement level should not jeopardize the integrity of the structure. This is why blended cements are recommended for use in bungalows and non-load carrying components of highrise buildings e.g., partition walls, finishings, external works – fencing walls, drainages, walkways, kerbs, etc.

vi. Some targeted users do not accept the usage of these local and innovative materials for constructing their buildings due to lack of adequate information about their characteristics. I encourage such people to get a copy of this inaugural lecture series for better understanding.

vii. I want to appeal to University Council and Management to make it a point of duty to send academic staff to at least one Local and International Conference every year. This will expose them to current trends in their areas of specialization as well as expose them to possible collaboration with their foreign counterparts for better research opportunities. This provision is already embedded in the Academic Staff Union of Universities (ASUU) 2009 agreement. The will to implement is the crux of my appeal in order to have a university system that can compete with others worldwide.

10.0 ACKNOWLEDGEMENTS

Alhamdulillah! Alhamdulillah!! Alhamdulillahi Robil Alamin. Glory be to Almighty Allah the Lord of the worlds. I thank Him most sincerely for His mercies and blessings at all times, especially for making today a reality. May He continue to shower His mercies and blessings on us all. Aamin.

I appreciate the Ag. Vice Chancellor, Prof. Mojeed Olaide Liasu and all the Principal Officers of the University for the opportunity given to deliver this inaugural lecture. Special thanks to formal Vice Chancellors of LAUTECH especially Late Prof. Akinola Murtala Salau under whom I served as Acting Head of Civil Engineering Department for two terms and Prof. Sulaiman Adeniyi Gbadegesin, during whose tenure I was promoted twice to Reader and Professor successively. My thanks also go to the University Inaugural Lecture Committee headed by Prof. Justice Emuoyibofahre.

My appointment to LAUTECH was facilitated by Rev. Canon, Prof. Emanuel Babajide Lucas. I thank 'Baba Lucas' as he is fondly called for his tutelage in making me a devout academic staff and for his mentoring. I appreciate Prof. J. O. Ojediran, Prof I. A. Adeyemi, Late Prof. J.A. Ogunrombi and Late Prof. T. I. Raji for their guidance and encouragement at the early stage of my academic carrier. I recall vividly the pamphlet given to me by Prof. Adeyemi with the title "You came here to teach" which opened my eyes to the fact that lecturing alone in the university cannot earn you promotion. It is either you publish or perish.

Special appreciation to my Ph.D. Supervisor- Prof. David. A Adesanya, M.Sc. Supervisor – Associate Prof. M. B. Olufowobi, B.Sc. Supervisor - Mr. Akinwunmi and all my teachers at the primary, secondary and university levels. They are the ones that moulded me to what I am today. Thanks indeed. I am also grateful to Late Dr. G.A. Alade of University of Ibadan, who was the external examiner for my Ph.D. Oral examination. He came to my rescue at the last minute when the previously appointed external examiner traveled out of the country. I thank Prof. Mrs. Taiwo Kehinde, Prof. Osunade, Prof Ajayi and Prof. Fadare - all of O.A.U. Ile-Ife for their assistance

during my Ph.D. degree program. I am immensely grateful to the management and staff of West Africa Portland Cement Company (WAPCO) Sagamu Plant, Ogun State for the opportunity given to carry out my PhD experimental works in their laboratories. I cannot forget the hospitality of the family of Late Dr. Fatai Aborode who provided accommodation for me in Sagamu during my Ph.D. experimental works.

I want to appreciate my collaborators both at home and abroad. I thank Prof. Mrs. Bola Babalola (DVC, OAU), Prof. Fagbenle, (Covenant University Ota) and Prof. Amu (Federal University, Oye-Ekiti), we were all Ph.D. candidates of Prof. D.A. Adesanya that convocated the same year, 2006. I equally appreciate Profs. Odusami, Idoro, Adenuga, Ameh and Dr. Soyingbe of Building Department, University of Lagos; for the excellent relationship during my sabbatical leave period over there. From University of Ibadan, I thank Profs. Dahunsi, B.I.O; Agbede, Coker, Ayo Ogunjuyigbe, Ayinuola and Ajagbe. Other colleagues to appreciate are: Profs Olusola, Ata, Aina and Ojo (OAU), Prof. Babatunde Olawuyi (FUTMINNA), Prof. Festus Olutoge (Trinidad and Tobago), and others too numerous to mention.

My journey to the University of South Africa (UNISA), Science Campus, Johannesburg; was facilitated by Prof. John Olaomi and my Host - Prof. Mrs. Bolanle Ikotun. They also made my stay in UNISA easy and memorable – I thank you both immensely. I appreciate the support I received from the staff of Civil and Chemical Engineering Department of UNISA (especially, Profs. Nthombeni Nocembo, Walied, Ilunga and Onyari Ednah; Mrs. Zakity, Mr. Rooney and Mama Sheila - the Secretary) during my one-year Visiting Research Programme. I also thank Prof. Yusuf of Electrical Engineering Department, Prof. Chris Enweremadu of Mechanical Engineering Department and Mr. Akinwale of the Works Department, UNISA for making my stay in South Africa wonderful. I thank Prof. Patel and Dr. Walied who provided the car we normally used for Zuhr Prayer outside the campus. Other members of the prayer group – Prof. Adekunle (OAU), Messrs. Shahidi, Aliu Adeleke, Olaitan, etc. are also appreciated. I must not forget Prof. Mrs. Bimbo Windapo of Cape Town University, South Africa for her hospitality during our (myself and my wife) visit to Cape Town.

I thank the Civilian Family beginning with Mrs. Eunice O. Fadahunsi (mama Civil) – we started the Civil Engineering Department in LAUTECH together in 1992 under the headship of late Dr.

G.A. Alade. I appreciate Profs A.A. Adegbola, S.O. Ojoawo, O. S. Oladeji, O. S. Oladejo, O. M. Osuolale and Drs J. R. Oluremi (incumbent HOD), J. A. Ige, S. O. Ajamu, R. A. Olaoye, O. K. Fagbenro, O. S. Olaniyan and Engrs. F. V. Onawumi and A. S. Ayanlere. All Technical and Secretariat staff of the department are also appreciated. Former staff of the department who had relocated to other universities are appreciated as well. They include Prof. A. A. Bello-UNIOSUN, Associate Prof. W. O. Ajagbe –UI and Dr. S.I. Adedokun – UNILAG. My thanks also go to members of the Departmental Inaugural Lecture Committee headed by Prof. S. O. Ojoawo. I also want to appreciate all members of the Cement and Concrete (CEMCON) Research Group, both at home and abroad, for your cooperation and support in all our activities. It is my prayer that the group will continue to progress beyond our imaginations. Aamiin.

All Professors in the Faculty of Engineering and Technology (FET) are appreciated commencing with Prof. J. O. Olajide-under whom I served as Deputy Dean for 2 years. Special thanks to Prof. O. O. Ogunleye for summarizing my CV. Thanks to Profs. S.O. Jekayinka – the Dean, K.A. Adebiyi (former Dean and present Rector, The Polytechnic, Ibadan), O.J. Oyelade, Z.K. Adeyemo, M.O. Durowoju, G.A. Ajenikoko, D.O. Araromi, E.O. Omidiora, S.O. Olabiyisi, D. O. Aborisade, E.T. Otunola, M.O. Ologunde, E.A. Akande and others. The 'Iron Ladies' are not left out- Profs. T.J. Afolabi, B.I.O. Ade-omowaye, B.A. Akinwande, M.O. Aremu, A.B. Adetunji and others. All members of the FET family are appreciated. My new neigbours in the Faculty of Environmental Sciences are also appreciated, they include – Prof. R.O. Rom Kalilu, Prof. M. A. Akintonde (former Dean), Prof. M.O. Jelili (the 53rd Inaugural Presenter), Prof. A.M.O. Atolagbe, Dr. Razak Ayinla, Dr. Sulaiman Olaniyan and others. I thank my people in Building Department too – Mrs. V. B. Akinlabi (Secretary), Mrs. O. F. Ramon, Mrs. V. N. Dike and our NYSC members – Mr. Sunday Otun, Mr. Hans Elaho and Miss Titi Agboola.

University-wide, special thanks go to Late Prof. Abass Olajire; Profs. G.O. Oyediran, A.A. Odunsi, A.A. Akingbade, O.O. Fawole, L.A. Sumonu, E.T. Ayodele, E.T. Oladipo, T. Ebijuwa, S. O. Adewoye, O.O. Oyegoke and Oba Prof. John Akintola – Alapa of Okin-Apa. The Nanotechnology group led by Prof. Lateef Agbaje is also appreciated for introducing us to the application of Nanotechnology in concrete. I am also grateful to Prof. Misbaudeen Abdulhameed for accommodating me for a week in Bonn, Germany; after the conference I attended in Munich in the year 2016. The efforts of Academic Staff Union of Universities (ASUU) in compelling

government to provide a befitting legacy for university education in Nigeria must be commended. I appreciate our leaders at national and local levels as well as all faithfull followers in LAUTECH Branch.

At professional level, I thank the President, Nigerian Institute of Building (NIOB) – Bldr. Prof. Y. D. Izam, Honourary General Secretary- Bldr. Adekanmbi Adelaja and Past President – Bldr. Kunle Awobodu. The CORBON Chairman and Registrar in person of Bldr. Dr. Samson Opaluwah and Bldr. Tunji Adeniran, respectively; are also recognized. The former Oyo State chairman- Dr. Akeem Wahab and incumbent chairman and secretary- Bldr. H. F. Olaniran and Bldr. Lade Olugbade, respectively are also acknowledged . I also appreciate Bldr. Tunde Lasabi, Bldr. Bimbo Kolade, Bldr. Mrs. Adenike Saad and Bldr. Mrs. Akinbile. Special thanks also go to Bldr. Prof. Bala Kabir – VC, ABU; Bldr. Prof. Emmanuel Achuenu - Rector, Delta State Polytechnic, Bldr. Prof. Sani Kunya, Bldr. Prof. Dada Martins and Bldr. Dr. Mrs. Adeosun and her team from Osun State University, Osogbo.

I cannot forget all my postgraduate and undergraduate students with whom most of the research was executed. I thank the Ph.D. candidates that completed under my supervision –Dr. Mohammed T. Audu (of blessed memory), Dr. Mrs. Blessing Orogbade, Dr. Emmanuel O. Ibiwoye, Dr. Oluwaleke Olowu, Dr, Rasheed Abdulwahab and Dr. Mutiu Kareem. My Master and B.Tech. graduates are also appreciated, notable amongst them are: Aladeloba Adesina, Akinloye Samuel, Sikiru Adetona Owonikoko, Michael Aborisade, Dayo Awodele, Monsurat Ajagbe (nee Olanrewaju), Zainab Babalola (Nee Abubakar) and Ibrahim Onifade.

I acknowledged the prayers, love and support of my spiritual family – LAUTECH Muslim Community (LMC) under the leadership of our Grand Imam – Prof. Tijani Abdulwahab. I thank the former LMC Chairman – Prof. Nurein Olawore, the incumbent Chairman – Prof. Rahaman Onaolapo, the Treasurer – Prof. Isah Ade Bello, the Financial Secretary – Prof, Maruff Adabanija, other Exco. members, and the entire LMC members. The Muslim Students Society of Nigeria (MSSN) LAUTECH Branch and Ogbomoso Area Council are also appreciated. Sincere greetings to Sheik Alimi Abdulwahab, Mallam Jamiu Yusuff, the Grand Chief Imam of Ogbomosoland- Imam Teliat Yunus Olushina Ayilara II and the entire Muslim Ummah in Ogbomosoland for the excellent relationship. Members of the Tawakalitu Muslim Women Organization under the leadership of Prof. Mrs. M.O. Bello are also not left out. Special thanks to Oba Tajudeen Abimbola Aminnullah – Iba of Orile-Abogunde.

My good friends are also appreciated amongst whom are Engr. Dr. Imam Taofeek Adekunle - Rector, Federal Polytechnic, Ayede, Mr. and Mrs. O.G. Bello, Mr. and Mrs. Abdulsalam, Mr. and Mrs. Adeniji, Alfa Idrees, Alh. Bashir Bello, Alh. Sodiq Sekengbede, Bldr. and Mrs. Solomon Omotunde, Prof. and Alhaja Oladepo, Rev. and Mrs. Segun Agbaje (Uncle Segun Photo – Ado) Bar. and Mrs. Lawal (Ado-Ekiti), Bar. Tunji Ologbonyo (Kabba), Mr. Bisi Ilesanmi, Mrs. Morenike Nwosu and a host of others. I thank the chairman of the Challenge community, Iwagba, Ogbomoso – Mr. O. Oyeleke and all Landlords and Landladies in the area for their cooperation.

I am grateful to my parents – Alhaji Rashidi Raimi Olatunji (he clocked 90 years in February 2023) and late Alhaja Mulikat Kehinde Raimi (may Allah grant her aljanat fridaus, Aamiin). I thank my senior sister and her husband-Alhaji and Alhaja Amodu and my junior sister and her husband-Mr. and Mrs. Makinde. From my father’s side, I thank Mrs. Musili Adeogun (Iya Alagbado), Alhaja Amudat Dairo (Iya Ikorodu), Late Mr. Muda Raheem Olatunji, Late Mr. Sulaimon Akanni Olatunji, Late Mrs. Risikat Adigun (Iya Adijat), The Arogundades, Ayinlas, Anifowoses. Adeoguns, Adiguns, Dairos and all my cousins and nieces. From my mother’s side, I thank Elder Thomas Odunbaku, Mr. Soji Odunbaku, Alhaji and Chief Imam Nureni Odunbaku, Mrs. Silifat Olanrewaju (Iya oni moin-moin) Mrs. Modinat Abisogun and others. I appreciate my in-laws: Alhaji and Alhaja Muibudeen Akinboro, Dr. and Mrs. Akeem Akinboro, Mrs. Khairat Taiwo Ajibola FCA as well as Kazeem, Gbenga and Morufu Akinboro and their spouses.

Finally, I want to appreciate my “Jewel of inestimable value” and darling wife – Alhaja Badirat Kehinde Raheem FCA. She has been very supportive and understanding in all my endeavours. May the almighty Allah continue to bless our union – Aamiin. I also thank my children - Sherif, Sailat, Ikramullah and Aisha; as well as my wards – Majeed, Kehinde, Faizah, Aisha and Mariam. You are all wonderful.

Mr. Vice Chancellor sir, and the audience, I thank you all for your rapt attention. May the almighty Allah grant you journey mercies back to your different destinations. Aamiin.

REFERENCES

Abigo. A., Madgwick. D., Gidado. K. and Okonji. S. (2012, September). *Embedding* Sustainable *Facilities Management in the Management of Public Buildings in Nigeria.* EPPM 2012, University of Brighton, Brighton, UK. Accessed on 13th May 2017 from http://www.ppml. url.tw/EPPM/conferences/2012/downioad /SESSON5_B/35%20E139.pdf.

Adebiyi, K.A. and Raheem, A.A. (2011). Appraisal of Safety Level in the Use of Equipment in Selected Construction Industries in Nigeria, Proceedings, CIB WO99 Conference on Prevention: Means to the end of Injuries, Illnesses and Fatalities, 24 – 26 August 2011, WASHINGTON DC, Pp. 1-15.

Adesanya, D.A. (1993). Effects of Particle Dimension on the Properties of Resin-Bonded Corncob Particle Boards, *Nigerian Journal of Technological Research*, 3:119-125.

Adesanya, D.A. (1996). Evaluation of Blended Cement Mortar, Concrete and Stabilized Earthmade from Ordinary Portland Cement and Corn Cob Ash., *Construction and Building Materials*, 10(6):451-456

Adesanya, D.A. (2000). The Characteristics of Laterite Bricks and Blocks Stabilized with Corn Cob Fillers. The Professional Builder, June/July, pp. 47-55.

Adesanya, D.A. (2001). The Effects of Thermal Conductivity and Chemical Attack on Corn Cob Ash Blended Cement", The Professional Builder, June, pp. 3-10.

Adesanya, D.A. and Raheem, A.A. (2009a). A study of the workability and compressive strength characteristics of corn cob ash blended cement Concrete. *Construction and Building Materials* 23:311–317

Adesanya, D.A. and Raheem, A.A. (2009b). Development of Corn Cob Ash Blended Cement. *Construction and Building Materials*, 23:347–352

Adeyemi, A.Y. (1998). An Investigation into the Suitability of Coconut Shells as Aggregates in Concrete Production. *Journal of Environmental Design and Management*, 1(1 & 2): 17-26.

Audu, M.T. and Raheem, A.A. (2015). Flexural Strength Characteristics of Beams Reinforced with Fan Palm under Various Exposure Conditions. *Innovative Systems Design and Engineering.* 6(4):1-10.

ASTM C150 (2002). Standard Specification for Portland Cement", Annual book of ASTM Standards (Revised Edition), 4(2):1-7.

ASTM C618 (2001). Standard Specification for Coal Fly Ash and Raw Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete", Annual book of ASTM Standards. 4(02):310-313.

Audu, M.T. and Raheem, A.A. (2015). Flexural Strength Characteristics of Beams Reinforced with Fan palm under Various Exposure Conditions. *Innovative Systems Design and Engineering*, 6(4):1-10.

Audu, M.T. and Raheem, A.A. (2017). Flexural behavior of fanpalm reinforced concrete slab. *Journal of Building Engineering*, 13:63-67.

Ayangade, J.A., Olusola, K.O., Ikpo, I.J. and Ata, O. (2004). Effect of Granite Dust on the Performance Characteristics of Kernelrazzo Floor Finish. *Building and Environment*, 39:1207-1212.

Blankendaal, T.P. Schuur, H.V., (2014). Reducing the environmental impact of concrete and asphalt: a scenario approach. *J. Clean. Prod*. 66:27-36.

BS EN 197-1, (2000). Composition, Specification and Conformity Criteria for Common Cements, British Standard Institute, 389 Chiswick High Road, London, W4 4AL,

British Standard Institution (1997): Structural use of concrete: code of practice for Design and construction. BS 8110. London, British Standard Institution.

British Standard Institution (2015): Concrete: Specification for constituent materials and concrete. BS 8500-2. London, British Standard Institution.

Chatveera, B., and Lertwattanaruk, P., (2014). Evaluation of nitric and acetic acid resistance of cement mortars containing high-volume black rice husk ash, *Journal of Environmental Management* 133:365-373.

Chowdhury, S., Maniar, A., and Suganya, O.M. (2015a). Strength development in concrete with wood ash blended cement and use of soft computing models to predict strength parameters. *Journal of Advanced Research*. 6:907-913.

Chowdhury, S., Mishra, M., and Suganya, O.M. (2015b). The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview, *Ain Shams Engineering Journal*. 6:429-437.

Daramola, S.A., Alagbe, O.A., Aduwo, B. and Ogbiye, S.A. (2005). Public-private partnership and housing delivery in Nigeria, Proceedings of African Union of Architects Congress, Abuja, Nigeria, 23-28 May 2005.

Elinwa, A.U., Ejeh, S.P., and Mahmuda, A.M., (2008). Assessing the fresh concrete properties of self-compacting concrete containing sawdust ash. *Constr. Build. Mater*. 22:1178-1182.

Elinwa, A.U., and Mahmood, Y.A., (2002). Ash from timber waste as cement replacement material Cem. *Concr. Compos*. 24:219–222.

Flower, D.J.M. and Sanjayan, J.G., (2007). Greenhouse gas emissions due to concrete Manufacture, *Int. J. LCA.* 12 (5):282-288.

Ganesan, K., Rajagopal, K., and Thangavel, K., (2008). Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete, *Constr. Build. Mater*. 22:1675-1683.

Gunasekaran, K, Annadurai, R and Kumar, P.S. (2013) Study on reinforced lightweight coconut shell concrete beam behavior under shear, *Materials and Design*, 50:293-301.

Heikal, M., Abd ElAleem, S., and Morsi, W.M. (2013). Characteristics of blended cements containing nanosilica. *Housing and Building National Research Center HBRC Journal*, 9: 243-255.

Ikotun, B.D. and Raheem, A.A. (2021). Characteristics of Wood Ash Cement Mortar Incorporating Green-Synthesized Nano-TiO_2. *International Journal of Concrete Structures and Materials*, 15:(19):1-9. Doi.org/10.1186/s40069-021-00456-x

Ikotun, B.D. and Raheem, A.A. (2023). Influence of synthesized nanosilica on properties of wood ash cement mortar, Proceedings, The 3rd International Civil Engineering and Architecture Conference, Kyoto, Japan, March 17-20, 2023.

Jerabo, R., Monte, M.C., Fuente, E., Santos, S.F., and Negro, C. (2013). Cornstalk from agricultural residue used as reinforcement fiber in fiberecement production. *Ind. Crop Prod.* 43:832-839.

Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A.N., and Mirza, J. (2012). Reduction in environmental problems using rice-husk ash in concrete, *Constr. Build. Mater*. 30:360-365.

Kong, F.K. and Evans, R.H. (1987) Reinforced and Prestressed Concrete, 3rd ed. London, Chapman, and Hall. ISBN 0 412 38420 5, 508pp.

Lam, E.W.M., Chan, A.P.C., and Chan, D.W.M. (2010). Benchmarking success of building maintenance projects. *Facilities*, *28*(5 & 6), 290-305.

Mohamed, A.M., (2016) Influence of nanomaterials on flexural behaviour and compressive strength of concrete. *Housing and Building National Research Center HBRC Journal* 12: 212-225.

Mohseni, E., Naseri, F., Amjadi, R., Khotbehsara, M.M. and Ranjbar, M.M., (2016). Microstructure, and durability properties of cement mortars containing nano-TiO2 and rice husk ash, *Constr. Build. Mater*. 114: 656–664.

National Building Code (2006) “Building Regulations”, LexisNexis Butterworths, Ohio.

NIS 87 (2007) Standard for Sandcrete blocks, Nigerian Industrial Standard, Approved by Standard Organization of Nigeria, Lagos.

NBBRI (2006) NBBRI Interlocking Block-Making Machine, *Journal of Construction*, 1(1):15-17.

Okafor, F.O. (1998). Palm Kernel Shell as a Lightweight Aggregate for Concrete. *Cement and Concrete Research*, 18(6):901-910.

Olagunju, O.S. and Raheem, A.A. (2021). Effects of Hollow Sizes on the Properties of Sandcrete Blocks. *LAUTECH Journal of Civil and Environmental Studies*, 7(2):55-64.

Olakojo, S.A., and Iken, J.E., (2001). Yield Performance and Stability of Some Improved Maize (Zea Mays) Varieties. *Moor Journal of Agricultural Research*, 2 (1), 21-24.

Olanrewaju, A. A., Khamidi, M. F., and Idrus, A. (2011). Appraisal of the building maintenance management practices of Malaysian Universities. *Journal of Building Appraisal, 6*, 261-275.

Olasunkanmi H.O. (2022) Quantifying frequent building collapse and disaster risk reduction in Nigeria, Africa in Focus, Wednesday, April 2022 (https://www.brookings.edu/blog/africa-in-focus/2022/04/06/quantifying-frequent-building-collapse-and-disaster-risk-reduction-in-nigeria/)

Olowu, O.A., Raheem, A.A., Awe, E.M. and Bamigboye, G.O. (2014). Enhancing the Mechanical Properties of Lateritic Brick for better Performance. *International Journal of Engineering Research and Applications*, 4(11):01-07.

Oluremi, J.R., Raheem, A.A., Balogun, R.O. and Moshood, A.A. (2023). Early strength development assessment of concrete produced from cement replaced with nano silica activated Corn Cob Ash, *Materials Today*: Proceedings (In Press).

Omange, G.N. (2001). Palm Kernel Shells as Road Building Materials. *NSE Transactions*, 36(1):17-25.

Orogbade, B.O. and Raheem, A.A. (2018). Chemical and Physical Characteristics of Blended Cements Produced from Softwood Ash. *LAUTECH Journal of Civil and Environmental Studies (LAUJOCES)*, 1(1):1-7. DOI: 10.36108/laujoces/8102/10(0110)

Orogbade, B.O., Raheem, A.A., Amusan, G.M. Kareem, M.A. and Ibiwoye, E.O. (2021). Physico-Mechanical Properties of Blended Cement Produced from *Parkia Biglobosa* (Softwood) Ash. *UI Journal of Civil Engineering and Technology*, 3(2):1-8 2734- 3359 Online.

Oyebisi, S., Olutoge, F., Raheem, A.A., Dike, D. and Bankole, F. (2023). Sustainability assessment of cement concrete modified with bagasse ash and calcite powder, *Materials Today*: Proceedings (In Press).

Osunade, J.A. (2002). Effect of Replacement of Lateritic Soils with Granite Fines on the Compressive and Tensile Strengths of Laterized Concrete, *Building and Environment*, 37:491-496.

Raheem A.A. (2001). Fire Safety in Highrise Residential Buildings. *Journal of Applied Sciences*, 4(3):2087-2098.

Raheem, A.A. (2004). Evaluation of Accidents on Road Construction Sites: Case Studies. *Science Focus*, 8:51-56.

Raheem, A.A. (2006). Comparism of the Quality of Sandcrete Blocks Produced by LAUTECH Block Industry with others within Ogbomoso Township. *Science Focus*, 11(1):103-108.

Raheem, A.A. and Adewuyi, A.P. (2007). Design of Reinforced Concrete Made Easy, Emola-Jay Communications Inc. ISBN 978 - 31064 – 7 – 6, 146 pp.

Raheem A.A. and Aderounmu O.M. (2002). The Effect of Aggregate Sizes on the Strength of Concrete. *Journal of Science, Engineering and Technology (JSET)*, 9 (2):4041-4051.

Raheem, A.A. and Abimbola, S.A.A. (2006). Effect of Specimen Size on the Compressive Strength of Concrete. *USEP, Journal of Research Information in Civil Engineering (RICE)*3(1):55-64.

Raheem, A.A.; Nwakanma, E.O. and Ogunleye, K.O. (2008). Engineering Properties of Concrete with Palm Kernel Shell as Fine and Coarse Aggregates. *USEP, Journal of Research Information in Civil Engineering (RICE)*, 5(1):58-70.

Raheem, A.A. and Audu, M.T. (2013). Tensile Strength Characteristics of Fanpalm under Various Exposure Conditions. *Innovative Systems Design and Engineering*, 4(9), 85-90.

Raheem, A.A.; Osuolale, O.M.; Onifade, I. and Abubakar, Z. (2010a). Characterization of Laterite in Ogbomoso, Oyo State, Nigeria. *Journal of Engineering Research*, 15(2):73 -79.

Raheem, A.A.; Bello, O.A. and Makinde, O.A. (2010b). A Comparative Study of Cement and Lime Stabilized Lateritic Interlocking Blocks. *The Pacific Journal of Science and Technology*, 11 (2), 27-34.

Raheem, A.A. and Adesanya, D.A. (2011). A Study of Thermal Conductivity of Corn Cob Ash Blended Cement Mortar. *The Pacific Journal of Science and Technology*, 12 (2):106-111.

Raheem, A.A.; Falola, O.O. and Adeyeye, K.J. (2012a). Production and Testing of Lateritic Interlocking Blocks. *Journal of Construction in Developing Countries*, 17 (1): 35-50.

Raheem, A.A., Momoh, A.K. and Soyingbe, A.A. (2012b). Comparative Analysis of Sandcrete Hollow Blocks and Laterite Interlocking Blocks as Walling Elements. *International Journal of Sustainable Construction Engineering and Technology*, 3 (1), 79-88.

Raheem, A.A., Olasunkanmi, B.S. and Folorunso, C.S. (2012c). Saw Dust Ash as Partial Replacement for Cement in Concrete. *Organization, Technology and Management in Construction – an International Journal*, 4 (2), 472-478.

Raheem, A.A., .and Adenuga, O.A. (2013). Wood Ash from Bread Bakery as Partial Replacement for Cement in Concrete. *International Journal of Sustainable Construction Engineering and Technology*, 4 (1), 75-81.

Raheem, A.A. and Olowu, O.A. (2013). Production of Household Paint using Clay Materials. *International Journal of Engineering, Research and Applications*, 3 (2), 85-93. (Index Copernicus Impact Factor – 11.66) http://www.indexcopernicus.com

Raheem, A.A.; Soyingbe, A.A. and Emenike, A.J. (2013). Effect of Curing Methods on Density and Compressive Strength of Concrete. *International Journal of Applied Science and Technology*, 3 (4), 55-64.

Raheem, A.A. and Bamigboye, G. (2013). Establishing Threshold Level for Gravel Inclusion in Concrete Production., *Innovative Systems Design and Engineering,* 4 (9), 25-30.

Raheem, A.A., Adenuga, O.A. and Afolabi, O.A. (2013). Characteristics of Concrete produced with Lagoon and Atlantic Ocean Water., *The Pacific Journal of Science and Technology*,14 (1), 66-74.

Raheem, A.A. and Audu, M.T. (2019). Comparative Studies on Flexibility Characteristics of Steel and Fanpalm Reinforced Two Bay Concrete Portal Frames., *LAUTECH Journal of Civil and Environmental Studies (LAUJOCES)*, 2(1):11-21. DOI: 10.36108/laujoces/9102/20(0120)

Raheem, A.A. and Ibiwoye, E.O. (2018). A Study of Neem Seed Ash as Partial Replacement for Cement in Concrete. *International Journal of Sustainable Construction, Engineering & Technology*, 9 (2), 55-65.

Raheem, A.A. and Ige, A.I. (2019). Chemical Composition and Physicomechanical Characteristics of Sawdust Ash Blended Cement. *Journal of Building Engineering*, 21: 404-408. https://doi.org/10.1016/j.jobe.2018.10.014

Raheem, A.A. and Kareem, M.A. (2017a). Optimal Raw Material Mix for the Production of Rice Husk Ash Blended Cement. *International Journal of Sustainable Construction, Engineering and Technology*, 7 (2):77-93.

Raheem, A.A. and Olowu, O.A. (2013). Production of Household Paint using Clay Materials. *International Journal of Engineering Research and Applications*, 3 (2):85-93.

Raheem, A.A.; Olowu, O.A.; Awe, E.M. Ebokaiwe, G., Akinniyi, I.A., Bamigboye, G.O. and Busari, A.A. (2015). Assessment of Post Fire Structural Strengths of Normal Strength Concrete Subjected to Cyclic Thermal Loadings. *Civil and Environmental Research*, 7 (9):75-84.

Raheem, A.A. and Kareem, M.A. (2017b). Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement. *International Journal of Engineering Research in Africa*, 32:25-35.

Raheem, A.A.; Adedokun, S.I.; Adeyinka, E.A. and Adewole, B.V. (2017a). Application of Corn Stalk Ash as Partial Replacement for Cement in the Production of Interlocking Paving Stones, *International Journal of Engineering Research in Africa*, 30:85-93.

Raheem, A.A. and Audu, M.T. (2019). Comparative Studies on Flexibility Characteristics of Steel and Fanpalm Reinforced Two Bay Concrete Portal Frames. *LAUTECH Journal of Civil and Environmental Studies (LAUJOCES), NIGERIA*, 2 (1):11-21.

Raheem, A.A., and Ikotun B.D. (2019). Investigation of Workability and Compressive Strength of Wood Ash Cement Concrete containing Nanosilica., *Advanced Materials Research*, 1154:129-136.

Raheem, A.A. Olowu, O.A.; Aladeloba, A.E., Hungbo, A.A. and Akinsanya, A.Y. (2019). Assessment of Influence and Threshold Ratio of Titanium Dioxide and Calcium Carbonate as Pigments on the Physio-Mechanical Properties of Emulsion Paint. *LAUTECH Journal of Civil and Environmental Studies (LAUJOCES)*, 3(1):98-106.

Raheem, A.A. and Ikotun B.D. (2020). Incorporation of agricultural residues as partial substitution for cement in concrete and mortar - A Review. *Journal of Building Engineering*, 31:101428, 1-10. Doi.org/10.1016/j.jobe.2020.101428

Raheem, A.A., Olowu, O.A., Oluremi, J.R. and Ajibi, I.J. (2021a). Enhancing the Flexural Strength of Concrete using Recycled Iron and Steel Slag Aggregate. *LAUTECH Journal of Civil and Environmental Studies*, 7 (1), 36-45.

Raheem, A.A., Olowu, O.A., Hungbo, A.A. and Ibiwoye, E.O. (2021b). Effects of water cement ratio on strengths characteristics of concrete produced with Recycled Iron and Steel Slag (RISS) Aggregates. *Advances in Science and Technology*, 107:97-112.

Raheem, A.A., Ikotun, B.D. and Akinloye, S.O. (2021c). Effects of granite sourced from selected locations in Ogbomoso, Nigeria on the properties of concrete. *Advances in Science and Technology*, 107, 113-121. Doi.org/10.4028/www.scientific.net/AST.107

Raheem, A.A., Oriola, K.O., Kareem, M.A. and Abdulwahab, R. (2021d). Investigation on thermal properties of Rice husk ash-blended Palm kernel shell concrete. *Environmental Challenges*, 5:10028, 1-16. Doi: https://doi.org/10.1016/j.envc.2021.100284

Raheem, A.A.; Abdulwahab R. and Kareem, M.A. (2021e). Characterization and Effect of Nanosilica on Consistency and Setting Times of Metakaolin Blended Cement Mortar. *NanoPlus: Science and Technology of Nanomaterials*, 2:66-75. Doi.org/10.48187/stnanomat.2021.2.004

Raheem, A.A. and Anifowose, M.A. (2023) Effect of ash fineness and content on consistency and setting times of RHA blended cement, *Materials Today:* Proceedings (In Press).

Raheem A.A. and Wabara, C.I. (2002). Evaluation of Accidents on Building Construction Sites. *Journal of Advances in Environmental Sciences*, 1(2):22-29.

Ren J., Lai Y., and Gao J. (2018). Exploring the influence of SiO2 and TiO2 nanoparticles on the mechanical properties of concrete. *Constr. Build Mater*. 175: 277-285.

Sargın, S., Saltan, M., Morova, N., Serin, S. and Terzi, S. (2013). Evaluation of rice husk ash as filler in hot mix asphalt concrete, *Constr. Build. Mater*. 48:390–397.

Sharobim. K.G., and Mohammedin, HA (2013) The effect of nano-liquid on the properties of hardened concrete, *Housing, and Building National Research Center HBRC Journal*, 9: 210-215.

Standard Organisation of Nigeria (2000), "Standard for Cement", NIS 439. Lagos, Nigeria.

Stenfanidou M., and Papayianni I. (2012) Influence of nano-SiO_2 on the Portland cement pastes. *Composites*: Part B. 43: 2706-2710.

Udoeyo, F.F., and Dashibil, P.U., (2002). Sawdust ash as concrete material. *J. Mater. Civ. Eng.* 14 (2):173-176.

Wabara, C.I., and Raheem, A.A. (2001). Project Team Characteristics and Incidence of Claims in Construction Projects, *The Quantity Surveyor,* 36, 21-26.