THE EFFECTS OF INCLUSION OF BAMBOO (*Bambusa vulgaris* SCHRAD) AND ACRYLIC POLYMER ON THE PERFORMANCE OF SELECTED CONCRETE BUILDING COMPONENTS

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CERTIFICATION

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DEDICATION

This work is dedicated to God Almighty, in WHO resides all knowledge, power and understanding. Heis theAlpha and theOmega, thebeginning and the end.

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ABSTRACT

Concrete is used extensively in building construction. However, it is susceptible to corrosion, moisture migration, cracking, delamination and spalling is on the increase. These may be mitigated by components reconstitution with the inclusion of non-corrosive reinforcement and water repellent additive. Literature is sparse on the combined use of bamboo (*Bambusa vulgaris*) and Acrylic Polymer (AP) as means of arresting these deficiencies. This study was therefore, designed to investigate the effects of the inclusion of bamboo and AP on cement blocks, roof tiles and columns.

Portland Limestone Cement (PLC), sand, AP andbamboo culms were obtained locally. The culms were sun-dried to 8% moisture content, processed into $6 \times 10 \times 900\text{mm}$ strips and 2.0mm fibres. The strips and fibres were treated with bitumen (12.0% w/w) and NaOH (10.0% conc.), respectively. Blocks $(150 \times 150 \times 150\text{mm})$ at four bamboo fibre levels$(0, 0.5, 1.0, 1.5\%)$and AP$(0, 5.0, 10.0, 15.0\%)$ by mass of cement, roofing tiles $(810 \times 910 \times 1520\text{mm})$ and columns $(150 \times 150 \times 900\text{mm})$ reinforced with bamboo strips and ferrocement mesh were produced in three replicates. Binder:sand ratio of 1:3 was used for blocks and roofing tiles, while binder:fine sand:coarse aggregate ratio of 1:3:3 was used for columns at a constant water/cement ratio of 0.58. A $813 \times 914 \times 1524\text{mm}$vibration table was developed and used to agitate the roof tiles at a frequency of 1200 rev/mins. All composite samples were cured for 28 days except the blocks which were cured for 28, 45 and 60 days. Block density, water absorption, compressive, flexural, split tensile strength and microstructure arrangement were determined using standard methods. Accelerated ageing using Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) and effects of edge cracks on natural weathering of the roofing tiles were evaluated, while axial deflection tests were performed on the columns. All tests were performed according to ASTM, ACI and BS standards. Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Block density and water absorption were 1410-1880 kg/m^3 and 1.0-2.9%, respectively, while compressive, flexural and split strength were 22.9-29.6 N/mm^2; 4.0-9.9 N/mm^2 and 3.0-4.9 N/mm^2, respectively at 28 days; 26.2-39.2 N/mm^2; 6.4-10.9 N/mm^2 and 3.5-6.9 N/mm^2 at 45 days; 31.9- 44.9 N/mm^2; 8.3-11.7 N/mm^2 and 4.1-7.7 N/mm^2, respectively at 60 days. The best block property was attained at $1.5\,\%$ fibre contents and 10.0% AP with density, water absorption, compressive, flexural and split strength of 1410±57 kg/m^3, 2.8±0.1%, 44.9±2.6 N/mm^2, 12.1±0.9 N/mm^2 and 7.7±0.6 N/mm^2, respectively. The fibres and polymers created anchorage between the reinforcement and matrix. There was no significant difference in MOR (2.1–2.4 N/mm^2) and MOE (457.9–877.6 N/mm^2) after accelerated ageing tests. At 1.5% bamboo and 10.0% AP with ferrocement, there was no noticeable edge crack in the roof tiles after 24 months-weather exposure. Column axial deflections reduced from 3.6 to 0.3mm on inclusion of bamboo reinforcement and AP additive.

Reinforcement with bamboo and addition of acrylic polymer enhanced the dimensional stability, strength and durability of concrete blocks, roofing tiles and columns.

Keywords: Bamboo fibres, Acrylic polymers, Ferrocement, Cement composites

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CHAPTER ONE

1.0 INTRODUCTION

Shelter is among the primary need of every individual. Less than a 100 third world developing nations are facing problems arising from inadequate shelters because of unprecedented growth in population, urban migration, civil unrest, internal crises and others.

Nigeria is one of the most populous black nation in the world with an estimated population of 200 million. Itis among the fastest growing population globally and has about 7% rural-urban migration rate in the last 30 years (Abbass, 2012). Consequently, there is a need for basic amenities such as shelter in urban centres. The use of durable and affordable construction materials can deliver adequate housing under the current inflationary circumstances (Tacoli *et. al*., 2015).

Some of the oldest building materials in use in Nigeria are wood, bamboo, unfired clay and grasses for roofing. Some of these items are susceptible to moisture-induced decay; harbour pests and are not fire resistant (Viitanen *et. al*., 2010). Nigeria also depends heavily on imported ceiling and roofing materials (Saka and Olanipekun, 2020). Many of these materials are expensive and thus unaffordable to low income earners. In many instances construction is also done using steel-reinforced concrete and the ferrous metals are prone to corrosion (Smith and Virmani, 2000).

In view of the foregoing, it is expedient to develop affordable and durable building materials from locally available sources that are relatively lightweight, adaptable to modular construction and repair in service (Omoniyi and Akinyemi, 2012).Concrete reinforced with bamboo strips and fibres and ferrocement could satisfy these conditions (Sassu, *et al*., 2016).

1.1 Fibre Reinforced Concrete

Fibre reinforced concrete (FRC) is a composite material made up of fibrous materials embedded in concrete for the purpose of increasing the structural integrity. The fibres tend to be short, discrete, uniformly distributed and randomly oriented

(Archila et al., 2018). Fibres commonly used include steel fibres, glass fibres, synthetic fibres and natural fibres each of which has different effects on the concrete.

The fibre system provides superior resistance to cracking in hardened state in concrete. They also tend to provide maximum resistance to damage from heavy impact. Fibre-reinforced concrete products are used primarily for wall constructions.

In recent years, however, due to environmental concerns, the trend has been towards using natural fibres for concrete reinforcement. One of the major sources of natural fibre which has been highly investigated over time is bamboo. It has now been established that bamboo of various species can be used as replacement for steel in concrete reinforcement (Dinesh et al., 2014). It has also been reported that addition of acrylic polymer in the concrete can enhance its performance (Christopher, 2007).

1.2 Ferrocement

Ferrocement is a composite of reinforced mortar (or fromlime or cement, water and sand) and trowelled over an armature such as steel mesh, woven mesh, metal fibers and natural fibers such as bamboo which could be used for construction of flat surfaces, domes, extruded shapes, vaults, or free-formed shapes (Sakthivel and Jaganathan, 2011). It can be fabricated with few skilled labours and uses materials that are easily available. It has been proven suitable for different industries such as housing, marine and agriculture.

In-service ferrocement's structures achievement as a building material relies on its toughness and strength in the face of environmental situations. It can resist abrasion, ageing from weather elements, chemical attacks, cracking and other destructive processes. The durability of ferrocement is dependent on the ability of the component materials which include wire mesh reinforcement and mortar to bond together properly(Sakthivel and Jaganathan, 2011). In the same vein, the attachment between these components over lengthy duration when exposed to severe environment must be maintained. One way of enhancing this ferrocement's strength and durability is through alteration with polymer or latex of the mortar in the ferrocement products. Polymer or latex modification is an efficient method of changing or improving the characteristics of hardened mortars and concrete such as deformability, strength, bond, waterproofing and durability (Talib *et al*, 2013).

With the aforementioned challenges, a low cost composite construction material that would solve these problems needs to be developed.

1.3 Statement of Problem

Adequate provision of shelter to an ever-increasing population is a problem that cannot always be solved using only standard building materials such as imported roofing materials (corrugated iron sheets and others) as well as conventional cement bricks. Although, these two materials that are known to be durable and structurally stable andare becoming progressively costly (Ugochukwu and Chioma, 2015). The resultant effect is that essential building projects are unfinished, abandoned or too expensive when completed. This precarious situation may be attributed to the limited foreign exchange needed for importing some essential building components (Ayodele, 2011). The development of these materials locally is capital intensive; urban centered; and dependent on imported items. Furthermore, the expenses of carrying and distributing these construction materials from urban centers to rural hinterlands are excessive due to the scarcity or increased fuel expenses and underdeveloped transport status such as road network (Stanley *et. al*., 2014).

1.4 Aim

The aim of this study was to evaluate the effects of *Bambusa vulgaris* (Schrad) fibres and acrylic polymer inclusion on the performance of wall, brick and roofas concrete building components

1.5 Objectives

The specific objectives were to:

i. Evaluate the physical, mechanical, thermal, micro-structural and elemental compositions of bamboo fibre-reinforced cement composite reinforced with acrylic polymer.

ii. Investigate the potential of bamboo reinforced acrylic polymer modified ferrocement structural components for crack control.

iii. Evaluate the edge crack and delamination of a model structure roofed with bamboo reinforced acrylic polymer modified ferrocement material.

iv. Evaluate the effects of accelerated ageing on bamboo reinforced acrylicpolymer modified mortar samples

1.6 Justification

Reinforced concrete used in conventional building construction is heavy and susceptible to durability problems of crack propagation and spalling due to moisture ingress (Mukhopadhyay et al., 2006). The deployment of natural fibres such as bamboo as reinforcement has been reported to mitigate crack propagation while incorporation of polymer admixture is known to curtail spalling (Archila, *et al*. 2018; Kim and Park, 2017). Natural fibres are readily available, renewable and cheap to process when used as reinforcement in cement composites. Its application could provide a cheaper means of obtaining improved reinforced cement composites in comparison with the conventional steel bars. Similarly, ferrocement structures have been adjudged to be lightweight with similar strength properties as the traditional reinforced concrete (Yardim, 2018). Therefore, its adoption as a building material will proffer solution to the heavy weight status attributed to traditional reinforced concrete.

1.7 Scope of the Research

The scope of this research covers the use of treated bamboo (*Bambusa vulgaris* SCHRAD) strips and fibres as reinforcement in the emulsion based acrylic polymer modified matrix for the construction of ferrocement building elements.The building elements considered were walls (bricks), roofs and columns. The physical properties, mechanical properties, thermal performance, microstructural analyses and elemental composition tests on the developed cement based composites weredetermined.

CHAPTER TWO

2.0 LITERATURE REVIEW

Building materials have been used since the beginning of the World. The first record of such was found in the Holy Scriptures in which the Israelites were made to build with earth and rocks for the Egyptians. Others include the Tower of Babel and Jericho walls all dating back to over 2000 years ago. In the old civilisation as well, renowned structures such as the Coliseum was built with clay and stone during the Roman Empire. Overtime, building materials had evolved and could therefore be classified into two types namely; low cost indigenous and conventional types.

2.1 Low Cost Indigenous Building Materials

There are numerous indigenous materials used in building construction. Examples are:

2.1.1. Wood

Wood is a hard fibrous material that forms the main substance of the trunk or branches of a tree or shrub used for fuel or timber. It is also known as a porous and fibrous structural tissue found in the stems and roots of trees and other woody plants.It is an hygroscopic, anisotropic, renewable, heterogeneous and permeable biological composite material with extreme physical complexity and chemical diversity (Gordon, 1991).

Freshly cut wood has to be seasoned to remove water soaked in it by drying them before its eventual usage. Dry wood is less susceptible to decay and rot, it is light and easy to transport, treatment with paints and preservatives are therefore more efficient. Seasoned dry wood has more strength and ease or workability than the wet one. It can be dried either in a kiln or openly dried. Despite the seasoning process, it is not completely dry but has a moisture content ranging from 5 – 20% which is dependent on the drying time and method used(Woodford, 2017).

Wood is classified into two, i.e. softwood and hardwood(Duggal, 2008).Both are commonly used for construction of houses, boats and furniture. Wood in its natural converted form is referred to as either timber or lumber when used as construction material. Another set of wood products is engineered wood made from wood strands, fibers, and veneersetc that are glued together.Examples include particleboards, fiberboards, oriented strand boards, glue laminated timber.Some of the advantages of wood and wood products includesustainability, simplicity of construction, carbon-capture benefits, insulation and enhanced air quality.

Despite these benefits, the use of wood products has some disadvantages which include fire risks, building code limitations and structural limitations. Being an hygroscopic material, it takes in water leading to swelling mostly during the raining seasons. However, as the dry season sets in, it loses majority of the moisture thereby resulting into wet and dry cycles over the years. These often eventually destroy the wood products. Availability of wood as a construction material is also currently being affected by deforestation owing to its extensive use for various purposes. This has encouraged the drive to explore and utilize other non-woody materials such as natural fibres and bamboo.

2.1.2. Bamboo

It is believed that the word "bamboo" originated from the Dutch or Portugese language with linkage to Malay or Kannada dialect (Soreng*et al*., 2015). It is a form of grass having internodes, nodes and diaphragm as its anatomy. The regions of the internodes are usually hollow, while thevascular bundles located within the cross section is littered within the stem in place of the cylindrical pattern. The dicotyledonous woody xylem and secondary growth wood are absent in bamboos. The absence of the later is responsible for the columnar instead of the tapering pattern (Wilson and Loomis, 2004). Bamboo is among one of the fastest growing plants available in the world because of its distinct rhizome dependent network. It can grow to 910mm within a 24 hours period at a rate of 40mm per hour (Lakkad, 1981).The rapid growth and its unique tolerance for small lands, make it a good material for carbon sequestration, afforestation and greenhouse gases emission mitigation. Bamboo provides exceptional bending and elastic modulus features with an incredibly high fibre content (ILO, 1992).

Bamboo has been reported to possess a tensile strength up to $40kN/cm^2$ and has the ability to absorb energy. It has only a little content of lignin but it is majorly made up of silicic acid which provides the needed hardness and durability to the shoot system. The composition of the tissue is 51% parenchyma, 40% fiber and 9% conductive tissue which provide the reason for its flexibility and outstanding strength(Schroder, 2021).

Bamboo is easy to cut, maintain, repair and re-positioned without using sophisticated machines. Its hollow circular cross section makes it convenient for handling, transporting and storing and for this reason, it is known as a light building material (Schroder, 2021). It can also be easily worked upon to create the needed shape, length and bend for the desired applications (Jain, 2017).

Bamboo can be used as construction material by structural frame method similar to the common timber frame design. It has been used for floor, walls and roof by interconnecting each piece together for good structural stability. It has found application as a material for foundation construction after appropriate treatments have been applied to it. One form in which it has been used for foundation include when its in direct contact with the ground surface. Another form is when it is attached to a pre-formed concrete footing while others are as bamboo piles and as concrete columns. Posts and beams are the major uses of bamboo as a wall building material. It provides the important structural frame for subsequent development of the walls by being positioned in such a way that it could withstand natural forces. Thereafter, it is in-filled in order to supply the required stability and strength to the built walls. It is also one of the major roofing materials which give a sturdy feature to the structure. The roof from bamboo materials is made up of rafters, trusses and purlins. It is similarly used as a scaffold material because of its ability to bear heavy loads. It involves using bamboo canes that are lashed to each other through many ropes. The tying is done in such a way that forces acting downward vertically place the nodes within the lashings(Jain, 2017).

Some reported advantages of bamboo include its tensile strength (about $40kN/cm^2$) which is said to be higher than that of steel based on its fiber orientation which runs along the axial direction. Bamboo can resist temperature of about 4000^oC

because of the predominant presence of water and silicate acid. This makes it to have an efficient fire resistant property (Jain, 2017).

The various species that are in existence are easily identified by their root system comprising of amphodial, monopodial and sympodial (Awalluddin *et al*, 2017).Some *Bambusa* species in existence are *Bambusa balcooa*, *Bambusa vulgaris*, *Bambusa tulda*, *Bambusa teres*, *Bambusa giganteus*, *Bambusa multiplex*, *Bambusa oliverian*. *The Dendrocalamus species available are Dendrocalamus sinicus, Dendrocalamus giganteus, and Dendrocalamus strictus (Yeasmin et. al., 2017).*Others are*Acidosasa, Acidosasa chienouensis, Actinocladum verticillatum, Alvimia, Ampelocalamus, Apoclada simplex, Arthrostylidium, Arundinaria, Atractantha, Aulonemia queko, Bonia, Borinda, Cathariostachys capitata, Cephalostachyum pergracile, Chimonobambusa macrophylla*among many other species and genera.

In Nigeria, five indigenous varieties of bamboo have been identified; these are *Bambusa vulgaris* and *Oxystenanthera abyssynica*. The later attains between 8 to 12 meters during maturity while the former reaches up to 14 – 20 meters with a girth of about 20cm at maturity (Omiyale, 2003). Others are *Bambusa arundinacea*, *Bambusa tulda* and *Dendrocalamus giganteus* . It is vast majorly in the southern part of Nigeria as well as the Middle belt with fast growth patterns and high yearly re-growth after it has been harvested. These species in Nigeria have same morphological traits although they possess different sizes which are determined by the soil type and the age (Ladapo et al., 2017).

2.1.2.2 Bamboo Reinforcement in Concrete Structures

In Nigeria and other third world nations where concrete reinforcement is commonly utilized in building, steel's elevated and continuously rising price has made building very costly. This, combined with the political will, has turned into a mirage any designed low-cost, inexpensive building material by successive governments (Nwoke and Ugwuishiwu, 2011). This growth has initiated the search for alternative and appropriate substitute in concrete works for steel reinforcement. This quest for a cheaper option has resulted into the discovery of plentiful products existing in nature such as oil palm fibres, sisal, coconut fibres and bamboo which may be acquired in the neighbourhood using local manpower and technology at low price and low energy levels. The adoption of many of the locally accessible resources as a replacement for standard materials in strengthened concrete components can reduce building expenses by as much as 30% to 80%. The interest in these local products is heightened by the facts that they are not only deemed cheap; they are also "eco-friendly" (Nwoke and Ugwuishiwu, 2011).

In some areas, such as China and India, the use of bamboo as a building component has been ongoing for many years, but its relevance as concrete reinforcement has gained no prominence until the Clemson studies in U.S.. The U.S. study on the feasibility of using bamboo as the reinforcing ingredient in precast concrete parts was conducted for the first moment in 1964 at the experiment station for the Military Engineers (Francis and Paul, 1966). The crucial strength development phases were tailored to consider the reinforcement properties of bamboo such as the sizes of the strips and the nodes. These were utilised in order to evaluate the resistance to compressive loading capacity of bamboo reinforced precast concrete parts and the outcome showed positive results once the nodes were reduced and if the dimensions were adequate enough to sustain the applied load (Francis and Paul, 1966).

Bamboo has recently been considered for use in ground cement floor plates where the plates behave in-elastically even under heavy loads. Dinesh *et. al*., (2014) conducted an experiment using bamboo as concrete slabs and subjected them to concentric loading at the middle. Crack mode and elongation-load pattern was analysed. The result showed that at 16kN the first crack occurred accompanied with failure of the concrete surrounding the bamboo culms. Moroz *et. al*., (2014) evaluated the effectiveness of shear walls reinforced with bamboo by producing a bamboo reinforced masonry wall specimens and an unreinforced masonry wall specimens which were tested under varying load conditions. A sudden failure has been reported in the unreinforced wall, and the peak load is the same as peak deflection. It is evident that incorporating reinforcement from bamboo improves the unreinforced masonry ductility, as well as shear peak capability. Another study by Atul *et. al*.,(2014) considered the use of various adhesives such as Anti Corr, Araldite, Sikadur 32 Gel, and to Tapecrete P-151, pre-treat bamboo culms and studied their effect on the interfacial bond strength when used to cast concrete beams and columns. These were subjected to axial and transverse loads to determine their failure pattern and load carrying capacity. The results indicated that the gel had the finest bond while axial loading indicated that untreated bamboo reinforced concrete showed brittle nature with failure owing to slipping of the strips from concrete mass.

2.1.3. Laterite

The term "*laterite*" is a Latin word meaning brick. Buchanan (1807) used it for the first time and described it as a brightly coloured iron-rich substance found in a country in Southern Asian. They are commonly dispersed worldwide in high-rainfall areas, but particularly in Africa's inter-tropical areas (Patrick *et. al*., 2011). Lateritic soils are extremely weathered and modified residual material created by the weathering actions and disintegration of rocks on site in humid areas around the globe with heavy rainfall. They are formed by comprehensive and long-term weathering of the fundamental parent rock due to leaching of silica over a long span of life producing hydroxides, alumina and iron oxide rich soils. The iron hydroxides quickly get rid of moisture to form iron oxides when they are exposed to the atmosphere, thereby creating a powerful bond with other substances to form concretional laterite soil (Kasthurba *et. al*., 2014). The findings of Oyelami (2017) revealed that they possess sound and strong dry density and compressive strength which would enhance the durability of bricks made from them.

2.1.4. Sandcrete

The blending of water, fine sand and cement leads to formation of sandcreteblock which is yellowish-white and has distinct sizes and shapes after moulding. They are also masonry units that exceed the dimension indicated in support of blocks when used in its ordinary aspect. Therefore, the block can be produced also in strong and empty rectangular forms to be used in ordinary walls either as ornamental or cut open in distinct styles, designs, shapes, dimensions with different kinds for panel walls or sunbreakers (Anosike and Oyebade, 2012). They are commonly used as a walling unit in Nigeria and nearly all African nations. However, the quality of the sandcrete blocks generated differs from each sector owing to the distinct techniques used in the manufacturing and the characteristics of the constituent components. Sandcrete block walls are not normally intended to support loads other than their own weight (Awolusi, *et. al*., 2015).Alejo (2020) reported that sandcrete bricks produced from a mix ratio of 1:6 of cement:sand had compressive strength within the range of 3.56 – 15 MPa.

2.1.5. Earth

Earth-building methods have been recognized for over 9000 years. It has been used in all olden societies as building material, not only for residential houses, but also for religious structures.

Methods used in building with earth:

i). Adobe

Adobe is one of the earliest products used in the building industry. To improve the strength, the soil is moistened with water and chopped straws or any other natural fibres are mixed with it and drying takes place after placement in the required mould. It is usually moulded into blocks with uniformity that can be piled up to create brick walls. The best adobe soil to bond the fabric together will comprise between 15 percent and 30 percent clay, while the remaining are majorly from larger aggregate or sand. Too much of excessive clay will result into significant cracks and reduction; while less amount of it will lead to fragmentation. Sometimes a little quantity of asphalt or cement may be used as stabiliser in adobe to make it versatile when the climate is excessive. By placing in a hydraulic or leverage press, adobe blocks are formed. Other methods include placing in moulds and then dried (Illampas *et al.*, 2009).

Also, to produce an exotic rich coloured floor surfaces, the adobe could be mixed with colourful clay substances and painted with natural oil. Houses made from adobe having significant roof space will require fewer servicing than if the sides are open in order for wall preservation to keep the adobe off the ground. A number of earth buildings were laid with cement mortars on the exterior surface in a bid to preserve the adobe, however this technique has failed repeatedly because moisture passes through the voids in the hardened mortar readily and to evaporate becomes a challenge. Re-plastering or stabilizing frequently is usually done when used as an external plaster. It maintains heat and cool well as being a healthy thermal insulator, but they are readily demolished by earthquakes. In cases where the walls made of adobe are not very well insulated, some means of giving isolation are needed to preserve the comfort of the building. This is sometimes accomplished by building a dual wall in between with an air space or any other isolation. Another approach is to put outdoor insulation products (Vlad, 2011). An extensive study on some selected properties of adobe bricks conducted by Silveira *et al.*, (2012) revealed that the average compressive strength, modulus of elasticity and tensile strength ranged from 1.03 – 1.32 MPa, 147 – 225 MPa and 0.17 – 0.22 MPa respectively.

ii). Compressed earth blocks

Compressed earth blocks (CEB) are building blocks created from reinforced or unreinforced compressed earth. The compression varies from several hundred kilos to several tons. Because of the excellent increase in durability, unreinforced blocks are only used where nothing is accessible to reinforce the blocks. In relation to stability, the earth from which the blocks are to be produced is calibrated for durability, workability and survivability. When a brick is compressed, it loses 30% of its quantity. This is due to the press' mechanical pressure that drives out air pockets and aligns wet clay particles and compacts the clay around the sand particles. The compression can be produced with hand-operated presses that have been used for many centuries, and still today some individuals create the blocks by beating soil into a wooden mould with a stick. Modern machinery can also be used in urban regions or for big multi-house locations, with hydraulics powered by diesel, gas or electric engines. "Rammed earth" is a comparable way, whereby a structure is created as one constant mass of compressed earth (Waziri and Lawan, 2013). The investigation of Bei and Papayianni (2003) revealed that the compressive and flexural strength of compressed earth bricks made from soil and earth mortar ranged from 1.94 – 3.21 MPa and 1.13 – 1.83 MPa respectively.

iii). Rammed Earth

First, a temporary frame is constructed; generally out of wood or plywood, to act as a mould for the required form and size of each segment of the wall. The frames must be durable and well supported, and the two opposing wall sides must be fitted together to avoid the elevated compression forces concerned from squeezing or deforming. Rammed earth is a wall-building method that involves compaction of mixed blends of earth soils at various stages between layers. Exactly 15-25 cm deep soil layer is appropriate for this method. As each shape is filled in, a different shape is put above it and process is repeated again. The technique continues until the wall attains the necessary dimension. Forms can be removed as rapidly as the upper layer takes shape, due to the ability of the compacted earth wall supporting its self-weight (Ávila *et al*., 2020).

Pneumatic rammers are used by this set of earth builders to compress the soil within the shapes or hand ramming pole could be used as well. The soil mixture among clay, sand and aggregate must be reasonable enough. The content of moisture and clay from the rammed earth is relatively low relative to that used for mud brick or other methods for soil based construction. When adding a small amount of cement to the mixture, various ranges of soils is suitable. The phrase recognized as' stabilized rammed earth' depicts a strengthened masonry material with an impressive thermal performance. Drying takes some minutes to be completed, and full curing can take up to two years. With increased curing duration, compression strength increases, and exposed windows should be shut to prevent damage from water (Canivell *et al*., 2020).Araki et al., (2016) reported that the tensile strength of rammed earth samples produced from a blend of lime and soil ranged from 15 to 20% after 28 days curing.

iv). Earth bags

Recently, the use of soil-filled sacks (earth bags) for construction has been resurrected as a significant natural building method. Polypropylene or burlap is the most frequently used sacks. It can be noted that the army is using sandbags to build obstacles against the climate and invasion from oncoming enemies. They have also been used in the past days in storms. From volcanic rock to adobe soil, everything can be used to fill the pockets and create on-site natural, earth-based building blocks. The fill material can either be wet or dry, but a more stable structure is created by the moistened material. An efficient technique is to use site excavation material to construct the base of the bag and/or walls (Geiger and Zemskova, (2015). Barbed wire is often placed between them in order to improve stiffness between each line of containers. Sometimes cords are woven around the sacks to inter-link each other, helping to keep the interwoven network together with additional strength capability infused. Typically, plaster, stucco or brick are used to complete the construction both to get rid of water and to prevent any deterioration through solar radiation. For urgent shelters, temporary or permanent housing, farms or most conceivable tiny to medium-sized buildings, this construction technique can be used. The walls can be bent to improve lateral strength, forming round spaces and vaulted ceilings like an igloo or towers (Daigle *et al*., 2008). The result of the study by Vadgama and Heath (2010) showed that the compressive strength of unstabilised earthbag is 1.7MPa which is governed majorly by the bagging materials properties.

2.1.6. Clay

Clay has been in use for over 10,000 years as a building material and provides the same benefits as contemporary construction material. It helps to produce a conducive microclimate at home that is healthier for the occupants. As a natural material, it has the valuable trait of regulating humidity and temperature. As a building material, the air humidity level remains at around 50 percent indoors. Even when it comes to temperature, it has better advantage because of its capacity to take in heat, which enhances steep temperature slumps. Furthermore, lower energy is needed to generate a pleasant sensation of heat. A good indoor climate subsumes the countless benefits of clay building (Nidri, 2014).

Clay can be blended with cellulose fibres or other materials to produce a durable building material. Such fibres include jute, reed, straw and wood chips that optimize the product for distinct uses. Clay building material works on protected ancient structures as well as repairs. Different forms in which it is used include as clay tiles, blocks and plaster, beaten clay and prepared to use clay mortar which products are of unburned clays (Wuppertal, 2014). When clay is altered by burning with elevated heat, the products are called ceramics. During heating, water is pushed off, some mineral re-crystallization takes place, and glass is produced from the quartz sand in the clay. The product is a material that is difficult and insoluble. The higher the firing temperature, the more crystallization happens and the more glass is created, leading in higher hardness and density.Žabičková *et al* (2016) in their experiment to study the tensile property of unfired clay bricks made from common clay soil showed that the tensile strength was 0.45MPa.

2.1.7. Coconut tree

Coconut palm (*cocos nucifera* L.) is regarded as the tree of life as well as porcupine wood (Anoop*et al*., 2011). The two types of coconut fibres that can be extracted and processed from coconut trees are the white ones which could be gotten from the non-matured coconuts and the brown fibre types which are obtained from the matured coconut. The later are strong, possesses high abrasion resistance and thick. But the white ones are finer and smoother but weaker. The wood from the tree is usually durable and hard with minimal volumetric changes over a long period of time. It is located along beaches in Lagos and as well in the North central region of Nigeria. It can also be found within the Asia-Pacific region of the world. Every part of coconut wood can be developed into commercial products.

High density coconut woods which are mostly sourced from the stem perimeter are usually used as load bearing structures such as joints and trusses. In addition to these, coconut wood could be used as poles, floor tiles, telecommunication and power poles, girts, railings and balustrades (Lockyear and Ross, 1983). Due to its beautiful natural appearance and attractive grain, it has also found applications in furniture industries. It could be used to produce an outstanding structural componentsuch as wall lintel, ceiling and towers. It is also used as an overlay for the bathroom tank. It can be used as a structural barrieragainst wind erosion and sandstorm. Similarly, it does not decay easily unless it is exposed to excessive humidity (Odeyale and Adekunle, 2008). It has also been used for construction of purlins, trusses, doors, joists and window frames.

Coconut husk is also used as natural fibre reinforcement in cement composite. A study by Olorunnisola (2006) showed that thedensity of coconut-husk-cement compositeranged from 594 – 650 kg/m^3. MOE and MOR were 1104 and 1.48 N/mm^2 respectively while the compressive strength was 3.68N/mm^2.

2.2 Conventional Building Materials

2.2.1 Steel

Steel does not distort, bend, extend and contract with the weather. In contrast to concrete, it doesn’t require curing time to harden but attains strength instantly. Being a versatile substance, it possesses reduced weight but higher strength, it is pleasant to behold, it can be used for construction under extreme environmental conditions, it has similar quality, has demonstrated durability and has low life cycle expenses. These characteristics make steel a material to choose from. Metal has many characteristics and if correctly used and mounted, the metal may have a much longer life than any other material. However, this advantage is limited by the environment and human health.

To produce metal, it uses three and even eight times more quantities of raw materials and resources than the amount of metal actually produced. As a consequence, there is an enormous quantity of waste that lastly gets into the environment-air, soil and water (Ilze, 2011). Its excellent strength, uniformity, light weight, ease of use and many other desirable characteristics make it the material of choice for various structures such as steel bridges, high-rise buildings, towers and other constructions (Clark, 2002). Steel needs iron ore, carbon, calcareous, magnesium and other trace components to be mined. First, iron must be processed from raw ore to create steel. The iron ore is loaded into a blast oven together with calcareous and coke (heat-distilled carbon). Hot air and flames are used to burn the materials into pig iron; the impurities (slag) floating to the top of the molten metal. Steel is manufactured by regulating the quantity of carbon in iron by further smelting. Limestone and magnesium are added to remove oxygen and strengthen the steel. A peak carbon content of2% is required. At this point, other metals are also frequently added to create multiple steel alloys. These metals include magnesium, chromium, and nickel, which are comparatively uncommon and hard to obtain from the crust of the earth. The molten steel is either moulded straight into usable forms or retrieved from milled (Jong-Jin, 1998). Steel has the following strength properties; elastic modulus of 2x 10^6 MPa and shear stress of 0.57 times the yield stress (The constructor, 2021).

2.2.2 Aluminium

Aluminium, extracted from bauxite ore, needs a big quantity of raw material to generate a tiny quantity of final product. Bauxite is usually strip-mined in tropical rainforests, a method that involves the removal of vegetation and top soil from big fields of soil. The soil is substituted when mining is finished. The soil may then be permitted to return to the rainforest, but it is more probable to be used as a farmland. Aluminium manufacturing is a big consumer of electricity, which in turn originates from burning fossil fuels. The refined bauxite is blended in a kiln with caustic soda and heated to produce aluminium oxide. This white powder, in turn, must pass through an electrolytic response in which direct electrical current is used to separate the oxides and smelt the material into aluminium. The material must be heated to nearly 3000 ° F for this method to happen. The processing of bauxite into aluminium outcomes in big amounts of waste (called "mud") containing traces of heavy metals and other hazardous substances.

A by-product of the smelting method (called "potliner") includes fluoride and chlorine and must be disposed of as hazardous waste. Because aluminium has such a large energy content, it is best implemented where it can take benefit of its light weight, corrosion resistance and low maintenance. Although recycling of aluminium beverage containers is prevalent, only about 15 percent of the aluminium used in building is restored (Jong-Jin,1998). Aluminium is now used for a host of building and design apps and is the material of choice for curtain walling, window frames and other glazed constructions. It is widely used for rolling blinds, windows, exterior cladding and roofing, suspended ceilings, wall panels and partitions, heating and ventilation equipment, solar shading equipment and full prefabricated buildings (European Aluminium Association, 2003). It is a quite light material with a specific weight of 2.7 g/cm^3 which is one-third of that of steel. Aluminium is a good reflector which can reflect up to 95% of sunlight thereby reducing the internal heat within a structure. It is extremely thin with its thickness stated as 0.007mm (Azo, 2002).

2.2.3 Plastics

Bakelite is the world's first synthetic plastic and has been in use for over 100 years. Becauseof their distinctive and specially created range of characteristics including lightweight, flexibility in design,insulating characteristics and recyclability. Plastics are much sought-after in construction and design.Some plastics are waterproof because of their light weight and excellent insulating characteristics, others because they are thin and airtight because they are waterproof (Geert, 2013). Plastics are currently used in houses primarily in thin covers, panels, sheets, foams and tubes. Skilful use of plastics will expand the usefulness and life of standard construction products and assist them to operate more effectively and economically. Plastics applications include façade panels, exterior covers such as weather boarding, windows, rolling shutters, and carpentry. The interior covering includes wall coverings, floor coverings and ceilings and counter ceilings, roof coverings, tightness, dome and lighting elements as well as sanitary equipment and piping. It is also used as insulators (Constructor, 2017). Nylon which is a type of plastic has the following properties; tensile strength of 12400N/mm^2, flexural modulus of elasticity of 410000 N/mm^2, izod notched impact of 1.2, heat deflection temperature of 194 ^oC and water absorption of 1.20% respectively (Curbell, 2021).

2.2.4 Corrugated roofing sheet

Corrugated sheet is a universal replacement for traditional roofing material. It is often seen as a sign of a greater social status. Corrugated sheet occurs in several grades. Quality relies on the metal that is used. One of the most common type is the zinc corrugated roofing sheets which is affordable and readily available for use by intending consumers. Despite these merits, they are easily corroded after some years due to the continuous effects of rainfall and sunlight on its surface. It also transmits loud sound most especially during rainfall thereby discomforting the occupant of the building. It easily transmits heat when there is no presence of ceiling boards within the house. Galvanized sheet steel is another type of roofing sheet which can be assaulted by corrosion as the protective layer decays. Aluminium sheet is naturally shielded by its self-preserving oxide layer. Over time, it acquires a grayish colour and loses its reflective characteristics. These parameters depend on the durability of corrugated roofing sheets. The extensive use of corrugated sheet as roof cladding material is primarily owing to the reality that its characteristics are compatible with the lightweight conditions suitable for developing nations. In the long run, severe flaws occur, including bad heat insulation; bad noise insulation; deterioration of false ceilings as a consequence of condensation and the need to import the material (Thomson and Banfill, 2005).

2.3 Definition and historical background of ferrocement

Ferrocement could be likened to a type of concrete reinforcement where directly spaced, single or numerous layers of mesh or tiny diameter rods are fully integrated or encapsulated in mortar. Steel mesh is the most commonly used material as reinforcement in ferrocement. Other materials, such as organic or synthetic fibres and natural have been combined with metal meshes to strengthen ferrocement composites (ACI 549.1R, 1993). Amcor (2014) classified the historical development of ferrocement into the 1850s, 1940s and1960s (Sabnis, 1979).

In 1850s, a Frenchman, Joseph Lambot, was granted the patent for the manufacture of a cement ship using wire strengthening. This was after Portland cement growth (Jain, 2005). Ferrocement is the forgotten sister of the conventional reinforced concrete building. In the19th century, both were invented and patented in France. Its use in building was overshadowed by reinforced concrete. Architect Angus W. Macdonald created a technique of paneling, prefabrication and mass production of ferrocement construction parts called the Amcor System (Amcor, 2014). It was utilized in the construction of a row-boat made from woven wires and matrix. Joseph Monier a Frenchman in 1823 to 1906 manufactured cement mortar flower pots reinforced with chicken wire and exhibited this product at the 1867 World Exhibition in Paris. Monier became renowned as the reinforced concrete progenitor. For many years in Germany, reinforced concrete has been called' Monier Iron' and at that time, chicken wire was a handmade product which was too expensive in the then quickly growing industrial era. The period's technology was unable to cater for the time and effort required to create thousands of cables mesh. Big rods, however, were used to produce what is now known as reinforced concrete and for a hundred years the concept of ferrocement was almost neglected (N.A.S, 1976).

During the First World War, Nervi researched on ferrocements for boat building in the 1940s when steel plate scarcity necessitated a search for other ship construction products. Pier Luigi Nervi, an Italian civil engineer, researched and declared the characteristics of ferrocement. The fundamental basis for this new reinforced concrete material ferrocement is the well-known fundamental fact that cement mortars can withstand great stress in the surroundings of the reinforcement and that the magnitude of stress is dependent on the arrangement and distribution of the wire mesh throughout the concrete body. After Second World War, Nervi constructed two ships that are still in use today (Charles, 1969). Ferrocement applications continued up to 1960s in various countries which include Australia, Great Britain, China, India and New Zealand when its use declined mainly because labour costs were rising and competitions for thin walled parts were created as describedby Mario, Nerve’s son (Charles, 1969).

Nervi's success in the 1960's stimulated the beginning of worldwide ferrocement application in developing countries. The main single property of ferrocement, highlighted throughout its development was related to its high structural performance, which allowed the product to be applied to different construction objects from housing panels to ship hulls. Several academic commissions on ferrocement were established which were:

- Under the chairmanship of Prof. James P. Romualdi of Camegie-Mellon University, U.S.A., an Intergovernmental Panel was established by the USA National Academy of Science on the use of ferrocements in developing nations in 1972.
- Committee 549 was established by the American Concrete Institute (ACI) in 1974.
- The International Ferrocement Information Center (IFIC) was established in 1976 at the Asian Institute of Technology in Bangkok, Thailand and, in cooperation with the New Zealand Ferrocement Marine Association (NZFCMA), organised a weekly article outlet entitled "The Ferrocement Journal." Unfortunately, the newspaper stopped publishing in 2006. Furthermore, from 1981 to 2012, ten global symposia took place in different areas of the globe, Cuba was the host for the recent symposium called FERRO10.
- The International Ferrocement Society (IFS) was created in 1991 to encourage ferrocement use. The Ferrocement Model Code was launched in 2001. The code offers a document enabling CivilEngineers to study and model their ferrocement designs.
- The Ferrocement Society (FS) was established in India in 2011.

The Ferrocement Group ACI 549 is still the most effective international committee. The Group published a design guide for ferrocement in 1989. This guide is still the most important reference document on ferrocement and is widely used by most designers. In 2000, Professor Antoine Naaman of the University of Michigan produced the first and to date the only text book “Ferrocement and Laminated Cementitious Composites” (Jianqi, 2013). Despite the fantastic job of many study organizations and building companies, no significant progress was made in characterizing a second-generation ferrocement.

2.3.1Importance of Ferrocement as a Construction Material

Ferrocement varies from standard reinforced concrete because there is a greater proportion of steel to cement mortar. By modifying the ferrocement material of the mortar/steel proportion, it displays characteristics that are superior to either steel or cement mortar individually. The geometrically formed sections give ferrocement resistance to strength failure.

Ferrocement manufacturing method is quite simple with rapid construction of parts; it could be prefabricated and easily installed. It also does not require the use of heavy machineries, plants and equipments. It is the best material used for repairing of cracks of structures in services without necessarily destroying it. It require no formal training as the personnel to be used for its construction could be trained on site. Being a lightweight material, it has better structural performance than steel and with cost reduction of 15 to 50% less than other materials of construction. `

Maintenance is less frequent and could resist more sudden impact such as earthquakes and tremors than reinforced concrete which is why it is used more in countries prone to these occurrences. Useful in strengthening of reinforced concrete element by using ferrocement jacket which is very effective in increasing the cracking, ultimate loads and impact resistance of the conventional material. Ferrocement building components can withstand direct fire with a temperature values up to 756 ^{o}C for a period of 2½hours with no segregation in the surface of the elements facing the fire. The basic raw materials are available anywhere in the world (Al-Rifaie *et. al.,* 2014).

2.3.2 Constituent Materials of Ferrocement

2.3.2.1 Reinforcement Mesh

One of ferrocement's essential components is the wire mesh. Various types of wire meshes are nearly found worldwide. These consist mainly of slender wires, either weaved or welded into a mesh, but the main requirement is that they have to be handled easily and should be flexible enough to bend around sharp edges if necessary. First, the wire mesh and reinforcing rod role is to behave as a lath that provides the shape and supports the mortar's fresh state. Its role in the cured form is to absorb the tensile stresses on the framework that cannot be resisted by the mortar alone (Shruti *et. al*., 2013). The strengthening should be clean and free of harmful substances such as dust, rust, paint, oil or comparable substances. The most common strengthening used in ferrocement constructions is a wire mesh with tightly spaced cables. Common wire meshes generally have square or hexagonal openings. Different types of meshes such as those with square openings are accessible in weaved or welded form. Other types of reinforcement are also used for some special applications for specific performance or economy, such as expanded metal mesh (Shruti *et. al*., 2013). Types of mesh are depicted in Figure 2.1.

Woven mesh: consists of longitudinal cables that act as a barrier made of linked metal, fibre, or other transversely crossing flexible or ductile materials. The thickness of woven mesh may be up to three wire diameters due to the tightness of the weave and at the junctions there is no welding. Woven wire mesh is more versatile and simpler to use than welded mesh (ACI549.1R, 1993).

Welded mesh: it is manufactured at the junctions using longitudinal and transverse cables welded together. It has a greater rigidity than weaved and this is the reason for the lower deflections of the welded mesh in elastic phase. Welded mesh has more strength, highly resistant to being rusty, and has more structural stability than weaved mesh. Greater modulus and rigidity is its hallmark more than weaved meshes, resulting in lower crack spacing in the original part of the deflection curve (ACI 549.1R, 1993).

Hexagonal mesh: It consists of six-sided thin, flexible, galvanized steel wire. It is made of frosty strained wire weaved using this same form. Since no cables are constant in any direction, this form of mesh is more flexible than woven or welded mesh and is usually simpler to manufacture and use for curved constructions in particular. Sometimes they are referred to as the mesh of chicken wire. It has many distinct applications, such as fencing of animals and fence netting curves (ACI 549.1R, 1993).

Expanded metal mesh: Cutting thin gage steel sheets and extending them perpendicular to the slits could form this. This sort of mesh in the ordinary orientation provides approximately equal power but is much weaker in the direction in which the development took place. It can be used as an option to welded mesh, but in building with sharp curves it is hard to use (Jianqi, 2013).

2.3.2.2 Cement

Cement can either be made from natural lime stones or using calcareous and argillaceous materials artificially. The three parts of hydraulic cements are lime, silica and alumina. In addition, most cement contains small sizes of Fe_2O_3, MgO, SO_3 and alkaline. Over the years, the composition of Portland cement has evolved, seen mainly in the increase in lime composition and a minor decrease in silica composition. Beyond a certain quantity, an increase in lime content makes it difficult to fully blend together in the midst of others. As a result, there will be liberated lime in the clinker, leading to poor quality cement (Duggal,2008 and Neville, 2000). ASTM C150 (2007) classified cement into Types I - V and their respective strength characteristics and its specific applications were also included.

Type I: Type I is a Portland cement for general use suitable for all applications where there is no need for distinctive features of other types. It could be utilized in conditions where concrete is not exposed to soil and water attacks or unfavourable temperature condition but where heat could be generated through hydration. They are used for construction of masonry sections, pavements, water pipes among others (ASTM C150, 2007).

Type II: Type II cement produces not as much of heat at a reduced rate than Type I. Type II cement is appropriate in construction of big piers, deep abutments and tough retaining walls with this gentle hydration heat. This feature is especially important when the concrete is placed in warm weather. This type of cement will cost the same as Type I. Type II Portland is appropriate for use where precaution against mild sulfate attack is crucial, as is the case with drainage systems where sulfate concentrations in surface waters are higher than normal other than being extremely severe (ASTM C150, 2007).

Type III: This type of cement is similar to Type I, but it is fine grained and has an early strength that is relatively high. The compressive strength after 3 days curing is up to the results of the compressive strength after 7 days curing of Types I and II respectively. Similarly, its compressive strength after 7 days curing is equal to the 28 days results from the compressive strength values for Type I and Type II. It can be used for prefabricated concrete manufacturing and enables quick mould turnover. It can be used for emergency building, repair and installation of machine base and gate. It is used to remove forms as soon as possible or to bring the construction into service as soon as necessary. Reduced controlled curing period is guaranteed when used in cold weather (ASTM C150, 2007).

Type IV: Type IV uses small heat of hydration of cement to lessen the velocity and amount of heat generated. It increases potency at a reduced rate than Type I cement. Type IV cement is intended for utilization in large concrete buildings, which include large dams, where a critical factor is the temperature rise due to heat generated during curing (ASTM C150,2007).

Type V: is appropriate where resistance to sulfate is essential. Concrete exposed to groundwater sulfates and alkaline soil is best suited for this type of cement. It is not available in many locations (Wikipedia, 2014).

Cement is rarely used alone, but is used to bind sand and gravel (aggregate) together. Cement is used for the production of mortar for construction with fine aggregate or for the production of concrete with sand and gravel aggregates. The chemical reaction of hydration process results in mineral hydrates that are not very water-soluble and are therefore hydrophobic in water and chemical resistant. This enables setting in moist or underwater conditions and further protects the hardened material from chemical attack. The hydraulic cement chemical method discovered by ancient Romans used volcanic ash (pozzolana) with added lime (calcium oxide) (Wiki, (2017a). Cements can be used alone, but the usual use is in mortar and concrete where the cement is mixed with inert material known as aggregate.

Mortar is cement mixed with sand or crushed stone that must be less than about 5 mm in size. Concrete is a mixture of cement, sand or other fine aggregate and a coarse aggregate of up to 19 to 25 mm for most purposes. Mortars are used in walls or as ground renderings to bind blocks, blocks, and stone. Concrete is used for a wide variety of construction reasons. Soil mixtures and Portland cement are used as a road foundation. Portland cement is also used in the production of blocks, tiles, shingles, pipes, beams, railroad ties and numerous extruded products. The products are prefabricated in factories and are provided ready for assembly (Frederick, 2013).

2.3.2.3 Water

Some significant definitions of water are:

a) Drinking water: water appropriate for human consumption.

b) Recycled water: water handled to an acceptable threshold appropriate for its planned use.

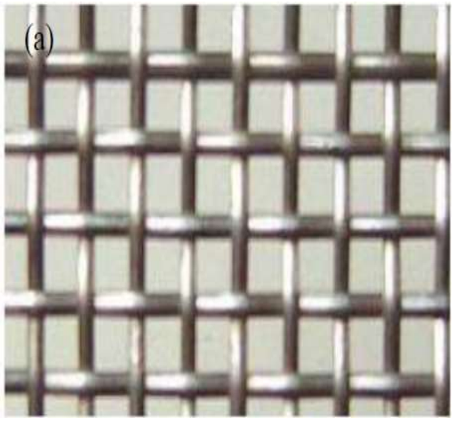
c) Black water: Toilet waste water, urinals directly contaminated with human excreta.

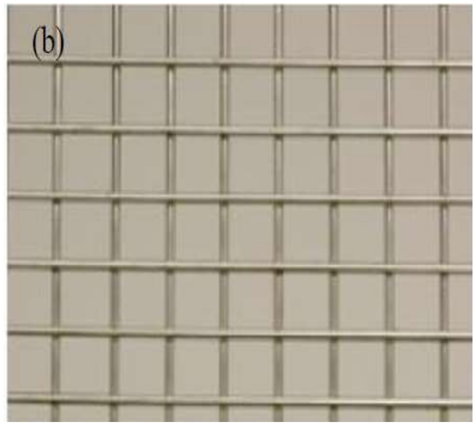
d) Gray water: Waste water from wash basins, showers, kitchens and laundries (Kucche *et. al.,* 2015).

Water is an essential component of concrete and it is required to mix concrete, cure and for aggregate washing. The impact of water on concrete is both positive and detrimental (Neville, 2000). Water used for mixing and curing concrete or mortar should be free from harmful chemical substances that could possibly have dangerous effects on concrete properties such as workability, strength development, setting time and durability (Babu *et. al*., 2018). There are countless present and fresh water sources available that may be suitable for use in concrete. It includes groundwater and treated wastewater among others. Due to the scarcity and lack of water in lots of places in the world, water authorities focus on identifying sources of fresh water. Such alternative sources include treated effluents that are useful to irrigate lands and in concrete preparation. If it does not contain brackish matter, water from streams, rivers and the ocean is also suitable (Kucche *et. al*., 2015).

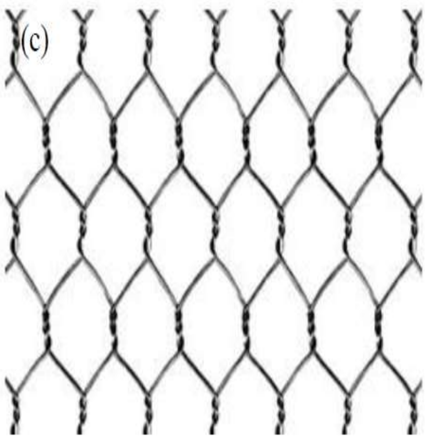
The following are standards and guidelines formulated for water usage in concrete applications:

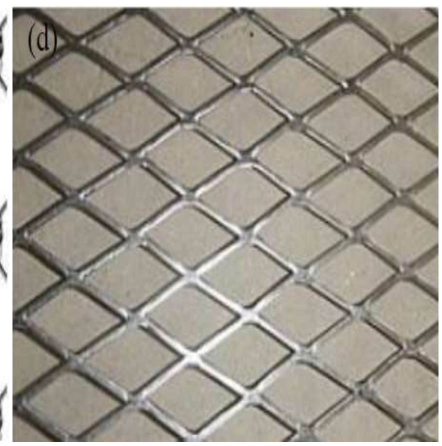
1. AS 1379 (2007) suggested the extraction of blending water from an appropriate source of quality. Water from ready-mix concrete plant is acceptable most especially in washout operations. This can be kept secure to prevent contamination from harmful products.
2. ASTM C-94 (1996) allows the use in concrete plants of non-potable water, the qualified restrictions to meet up with the necessities and non-compulsory limits are summed up in the standard. The levels of impurities permitted in wash water should be lower than the criteria for maximum concentration laid out in the code.
3. ASTM 1602M-(2006) describes water sources and offers criteria and trying rates intended for qualifying person otherwise mixed water sources. In a situation in which the owner's requirements differ from these specifications, the owner's condition must be provided.





(a): Woven mesh **(b):** Welded mesh





(c): Hexagonal mesh **(d):** Expanded mesh.

Figure 2. 1: Types of mesh(Source: Shruti *et. al*., 2013).

4. EN 1008 (2002) proposed water conditions suitable for concrete creation and explained methods for assessing its suitability. This standard includes the use of drinking water, water from concrete industry processes, water from underground sources, natural surface and industrial waste water for reinforced concrete, and seawater or brackish water for concrete manufacturing without reinforcement or other embedded metal. Sewage water is not suitable for production concrete.

2.3.2.4 Aggregates

Aggregates have fine textures and are used as building materials. Aggregate may be natural, produced or recycled (BS EN 13139 – 2013). The constituents of fine aggregate are sand from natural sources, sand produced and a blend of both. At the time of use, these materials are required to be free from lumps or crusts of hardened or frozen materials. The coarse aggregate comprises of crushed stones and gravels, crushed aggregates from hardened concrete gotten from construction and demolition wastes among many others (ASTM C 33-2003). Among these concrete parts, aggregates play a significant part in the new phase as they engage about 55 percent to 75 percent concrete quantity. Moreover, increasing the quantity of concrete aggregates corresponds to less use of cement, which has several positive impacts such as decreasing the price of concrete production, decreasing some of the durability issues of hardened concrete, decreasing shrinkage and cracking (Alexander and Mindess, 2010).

Additionally, aggregates have a significant impact on concrete strength by offering rigidity to the material that governs resistance to applied loads and undesirable deformations (Yahya, 2017). In ferrocement applications, only granular aggregate is used. These comprise of fine sand passing 2.34 mm sieve (well graded aggregate) which must be devoid of salt, raw matters and other harmful substances (Sakthivel and Jagannathan, 2011). High-quality uniformity and compactibility are attained through the use of finely graded, smooth native sand with utmost peak size of one third of the little gap in the reinforcing mesh to enable appropriate dispersion (Neelmani, 2013). In calculating the water needed, the wetness of the aggregate should be considered (Yousry *et. al.*, 2012).

2.3.2.5 Admixtures

Admixtures comprise of substances derived from chemicals that are blended with other constituents of concrete to alter some of the mixing characteristics (ACI, 2014). Chemical admixtures used in ferrocement serve as a water reduction agent that improves strength and decreases permeability, as well as an air intake medium that offers opposition to freeze and thaw cycles. They also act as containment of corrosion reactions between concrete and steel when used to strengthen it (Shruti *et. al*., 2013). The two main categories of admixtures are chemical and mineral admixtures. Chemical admixtures are applied to the mixture in small fractions during the mixing process to alter the characteristics of the blend. Examples are Super plasticizer and Chromium Trioxide (CrO_3).

The Super plasticizer admixtures are known as high range water reducing agents which give a considerable increase in workability of the matrix and concrete for a constant water cement ratio (Paillere, 1995). It is known that Chromium Trioxide (CrO_3) mitigates the constituents' interaction with steel strengthening. Mineral admixtures can decrease energy expenses, save raw materials and enhance the characteristics of concrete and matrix such as porosity, strength, permeability and toughness. Varieties of mineral admixtures are now commonly used in cement and concrete production; these include fly ash and silica fume. The former has elevated amount of amorphous SO_2 content and is made up of finely grained round molecules. (Jianqi, 2013).

2.3.3 Ferrocement Construction Methods

Four types of methods of ferrocement construction exist, these are:

1. Armature system: In this technique, on either side of which several layers of stretched meshes are attached, welding is done on the skeletal mesh to give the required shape. By pressing from one face and temporarily assisting from the second face, mortar is applied. It is also possible to administer mortar application by pressing in the mortar from both sides. The bars are in the center of the section in this technique and thus contribute to the static weight without any involvement with the strength (Wikipedia, 2014).
2. Open Mould System: For this type, through mesh or mesh layers and rods connected to an open mould made from wood strip lattice, mortar is filled in through

one area. For easy mould removal, observation and repair during the application phase of the mortar, a release agent such as grease or polyethylene lining is used which will lead to a closed but non-stiff and transparent mould. It is possible to compare this model with the closed version where the mortar is filled in from one area until it is possible to remove the mould. It enables viewing and repairing of part of the bottom of the mould if needed to guarantee the total encapsulation of the mesh (Bangladesh Building Code, 2012).

3. Closed mould system: Multiple woven layers are connected against the face of the mould putting them in place and filling in the mortar takes place. These could be separated as a constant part of a finished building after it had hardened or may remain in location. The releasing substance must be utilized to detach the mould for reuse (Darchdotme, 2014).

4. Integrated mould system: Plastering is conducted on either side or on both sides of these mould layers of meshes. As the name says, the mould continually remains an essential component of the completed building for floors and roofs. In order to make the finished item as a whole an essential structural unit, care should be taken to have a strong link between the mould and the layers filled in later (Buildcivil, 2014).

2.4 Cracks in Concrete

Cracking in reinforced concrete is a flaw. Indeed, the very foundation of reinforced concrete construction is that concrete should have substantial tensile strength and that adequate reinforcement should be supplied to regulate crack widths (Bamforth, 2007). However, problems may arise when cracks happen unpredictably or are of adequate magnitude to make the structure unserviceable.

The adverse effects of cracking can be regarded in three classifications:

i. Cracks lead to durability loss and subsequently a decrease in structural ability.

ii. Cracks that lead to the structure's loss of serviceability (such as water or radiation leakage, noise transfer or finish harm).

iii. Cracks that are esthetically inappropriate (Bamforth,2007).

2.4.1 Causes of cracks

Physical Changes:

a) Seasonal temperature and humidity: seasonal and daily changes in temperature and moisture content affect concrete properties. In most cases, the changes are reversible and do not cause any obvious problems. Porous materials such as blocks and concrete are affected by moisture. When moisture is absorbed, it leads to cyclic contraction and expansion of concrete because of changes in temperature and humidity which eventually could lead to crack development (Freeman *et. al*., 2002).

b) Initial drying: fractures could mostly be ascribed to original drying shrinkage that develops in the first few years after building. Most cement based materials often reduce in size when dried. This original reduction during seasonal modifications may be 50 times higher than the splits connected with motion (Freeman *et. al*., 2002).

c) Freezing and thawing: this can affect porous material such as often concrete exposed to saturation by moisture and to low temperatures. As temperatures fall below 0^oC, ice forms in the pores close to the surface which traps the remaining water and as further ice forms, the expansion causes the surface layer to break off which is referred to as "spalling" (Freeman *et. al*., 2002).

d) Efflorescence: Water also finds its way into walls because of inadequate damp proof proofing or through leaks which allow significant amount of soluble salts from the brickwork. As the water evaporates from the surface of the wall, the salt gels are left behind- a process known as efflorescence. Under certain circumstances, the gels are deposited below the surface causing spalling (Freeman *et. al*., 2002).

Chemical changes:

a) Sulfate attack: is an expansive reaction between Portland cement and water containing soluble salts which are usually sulphates of sodium, potassium and magnesium. The source of sulfate in brickwork is often the blocks themselves, and it is normally the plastering of mortar or cement that is affected. Salts can also be picked up by groundwater that comes into contact with earth retaining walls. Originally, the reaction leads to cracking and peeling of the mortar and rendering, but finally the total opening out of the masonry will result in general disruption, bowing, cracks and arching (Corral *et. al*., 2011).

b) Corrosion or oxidation of steel: this is a prevalent issue affecting pillars, fasteners, strengthening and structural steel work concealed in humid concrete products. Formation of rust or hydrated iron oxide is the major challenge which could result into multiple increments in size that could affect the surrounding materials thereby making them to move, crack and spread (Corral *et. al*., 2011).

Overstressing:

Walls and other components carry the loads imposed by the self-weight of the building materials and any external forces such as wind or snow. These loads are referred to as dead and imposed load. Cracking will occur wherever the total loading or stress exceeds the strength of the building material. This is seldom a problem in domestic buildings because most of the loading is compressive in nature and both blocks and concrete blocks are very strong in compression. Nonetheless, there may be overstressing locally when the joists as well as beams carry the concentrated loads from a tiny region (Freeman *et. al*., 2002).

Wear and Tear:

This is a combination of chemical changes that occur slowly over long periods and repeated cycles of temperature and humidity change. Although seasonal changes in temperature and moisture are essentially reversible in as much as the building materials returns to its original volume but repeated cycles can cause a crack to widen progressively. Because, masonry is very strong in compression, expansion can overcome friction and other forces and cause relative movement between individual blocks. This causes existing cracks to open up. However, as the wall cools or dries out, the tensile bond between blocks is too weak to return them to their original position. In addition, the crack may fill up with debris or dust while it is open. The net effect is a slight increase in width of the crack. Another cause of wear and tear of structures is persistent dampness, which can result into deterioration to plasterwork and mortar. Provided the dampness is identified at an early stage, the resulting damage is likely to be restricted to local debonding of the plaster. However, if the dampness goes undetected, it may give rise to processes such as sulphate attack and can eventually result in distortion and localised structural damage (Freeman *et. al*., 2002).

2.4.2 Crack Repair with Ferrocement Jacket

Whether owing to earthquake, impact or excessive stresses, the integrity and strength of a concrete structure is impaired when it is affected. In order to address the damage and prevent the entire system from eventually failing, actions are required immediately. Different approaches are available to address the damage, such as downgrading the building feature, destruction, rebuilding of a part or the entire structure, or stopping additional damage using rapid repair techniques. The most advantageous option is to repair the harmed part immediately due to the time and economic variables. Several research works have proven the effectiveness of ferrocement in repairing deteriorated concrete and in recovering the original load carrying capacity of the concrete columns (Chau-Khun *et. al.,* 2017). Due to enhanced knowledge and trust in the use of advanced repair machinery as well as the financial and environmental benefits of repairing or improving buildings relative to demolition and rebuilding. Therepair and reinforcement of present concrete constructions has become more common in the last decade (Jianqi, 2013).

Ferrocement jacketing in developing nations like Nigeria can be an efficient repair, recovery and reinforcement instrument for cracked reinforced concrete as its constituents are easily accessible. The use of the jacket in the reinforced concrete support is quite simple and requires no expert labour. Some of its enhanced characteristics include improved bending strength and resistance to tensile forces, durable, controls splinter and fracture and resistance to impact because of consistent reinforcement supply. Low material costs, unique characteristics for protection against flames and rustiness make it an optimal way to jacket (Mini and Veena, 2015; Kaish, *et. al.,*2016). Some researches based on restoration of deteriorated concrete provides a basis for understanding many repair methods that are applicable to ferrocement.

Nedwell *et. al.,* (1994) used ferrocement jackets to investigate the repair of eight simple square pillars, with two U shape welded meshes jacketing the damaged column. They discovered that the ferrocement retrofit layer on damaged pillars increases the column's evident rigidity and improves the ultimate load ability considerably. Besides, in Nedwells' investigation, the amount of steel surrounding the column increased both the stiffness and the ultimate stress by 40%. Ahmed *et. al.*, (1994) researched on the use of ferrocement as a product for retrofitting columns of masonry, application of ferrocement coating on bare masonry columns enhances the compressive strength quite significantly, the ferrocement coating increased the cracking resistance by spreading the stress across the entire surface area thereby eliminating stress concentration in any particular area. Yaqub *et. al.*, (2013) used ferrocement jacket to investigate and restore flame damaged square and circular structures. The results indicated that ferrocement jackets considerably boost the power and rigidity of post-heated strengthened concrete structures by confining the stress thereby improving the load carrying ability of the restored structures.

Shuai *et. al.*, (2017) worked on a laboratory study using alkali-activated slag (AAS) ferrocement to strengthen corroded reinforced concrete columns and also carried out direct tensile tests on them using multiple meshes. They reported that the reinforcement of AAS ferrocement increased the loading capacity of corroded columns by 37–72 percent. Column ductility enhanced by 77, 44, and 79 percent, respectively, under axial, tiny eccentricity, and big eccentric compression. This showed that through ferrocement jacketing the loading capacity of the corroded specimens were recovered to 97% of its original strength. By comparing the conduct of retrofitted samples with that of standard samples,

Kondraivendhan and Bulu (2009) assessed the effectiveness of ferrocement containment. The primary experiment variable assessed was the concrete's compressive resistance while all other parameters were kept constant. It was then observed that ferrocement confinement results in a 45.3-78 percent increase in resistance of the distinct classification of concrete samples considered as compared to the control samples. Furthermore, the concrete containment of ferrocement laminates resulted to the improvement of the axial and radial stress of the different grades regarded.

Mourad and Shannag (2012) tested square strengthened concrete pillars by preloading them to 0, 60, 80 and 100 percent, and eventually restored them using ferrocement jackets consisting of welded wire mesh in two layers which were enclosed in high-strength concrete; and then tested to failure. They stated that jacket reinforced concrete of four-sided pillars with this sort of ferrocement provided approximately 33% and 26% rise in axial load capacity and axial stiffness compared to the control pillars. Findings from the experiment also indicated that restoring similar reinforced concrete pillars (after failure due to preloading) with the same ferrocement jacket led to near recovery of their original load capacity and rigidity.

Hua *et. al*., (2016) evaluated the load carrying capacity and failure system using axial compression efficiency of eight square pillars enhanced with high- performance ferrocement laminate (HPFL) and attached steel sheets (BSP) frames. Their results indicated that the reinforcing layer functioned with the original blocks as a whole and that the load-bearing capacity increased significantly by 22%-52%, while the ductility also improved significantly. It could be seen from the aforementioned studies that there is a great prospect in the use of ferrocement in repairing damaged, failed and fire gutted structures.

2.4.3 Jacketing Techniques for Ferrocement used for Repair

Uniform strengthening allocation (wire mesh) leads to improvement of many engineering features such as tensile and flexural properties, durability, strain, defect regulation, opposition to failure and pressure, ductility and energy absorption features. Generally, the utmost time reducing and cheap alternative among all square strengthened concrete wall jacketing techniques is the square jacketing. Other techniques of jacketing include time-consuming alteration of the form as well as costly jacket with multiple forms.

However, square jacketing only offers confinement of stress in the edges to efficiently contain only a part of the cross section (Maalej *et. al*., 2003; ACI 440.2R-2008). Due to stress concentration and subsequent cracking at the corners, the square jacketing technique cannot efficiently provide lateral containment. Therefore, different researchers have proposed various approaches to solve this problem. For example, Amrul *et. al.,* (2013), whose concept was based on enhancing and decreasing levels of stress at all edges. This study adopted three types of jacketing technique (Figure 2.2) which included square jacketing with single layer wire mesh; square jacketing with single layer wire mesh and rounded column edges; and square jacketing with single layer wire mesh at each corner. The results showed that the system with rounded edges and a single layer of mesh was most efficient in improving the strength of the columns.

Kaish *et. al*., (2012) also developed three different square ferrocement jacketing techniques which include square jacket with one-layer mesh and rounded column angles; one-layer mesh of square jacket having shear switches in the center of the column base and one-layer mesh in addition to two more mesh layers at every corner and square jacketed. The findings revealed that the single layer mesh with shear switches had the best load supporting capacity of 50% more than the other types. Adnan (2016) assessed the performance of toughened concrete structures strengthened by using square and circular small-scale pillars with three distinct slenderness proportions as portion of the ferrocement layer under the operation of axial compression forces. It was reported that the load carrying capacity and resistance to lateral and vertical displacement is dependent on the slenderness of the columns with circular columns having 54% increase in capacity than the others. Abdullah and Takiguchi (2003) evaluated the response of four-sided columns using concurrent compressive and seismic conditions having six mesh parts using both four-sided and circular ferrocement jackets. It was discovered that the rehabilitated columns had 10% improvement in response to loading along the lateral direction.

2.5 Polymer Modified Concrete

Portland cement has been used extensively over the years after its discovery and production and has proven track record of making structures to be structurally stable and durable but there are certain limitations. One of its disadvantages is its brittleness when cured. The cured matrix has a limited capability to deform as a result of the movement. If the force of this movement exceeds the natural flexibility of the cured material, cracking is induced. Depending upon the extent, location within the building and type of structure cracking can be a costly process to rectify as well as looking aesthetically unpleasing (Baoshan *et. al*., 2010 and Siddiqi *et. al*., 2013).

Concrete is porous due to interconnected voids created during its hydration. Hardened concrete is a direct hydration product, a reaction between water and cement particles, which leaves interconnected pores when the capillary water dries out. The access points for chemical substances, gases, vapour and liquid water are the voids which could be detrimental to concrete if conditions are favourable to the environment thereby affecting the strength (Siddiqi *et. al.,* 2013). Some of the other disadvantages of cement mortar and concrete are comparatively delayed hardening, poor tensile strength, shrinkage, and low chemical resistance. Multiple efforts to utilize polymers to decrease these disadvantages have been reported. One of such attempt is polymer modification of mortar or concrete with additives such as latexes, water-soluble polymers, fluid resins, and monomers (Hirde and Omprakash, 2016).

Polymers are a large category of numerous small molecules identified as monomers, which can be connected together to form lengthy chains, making them known as macromolecules. A normal polymer consists of tens of thousands of

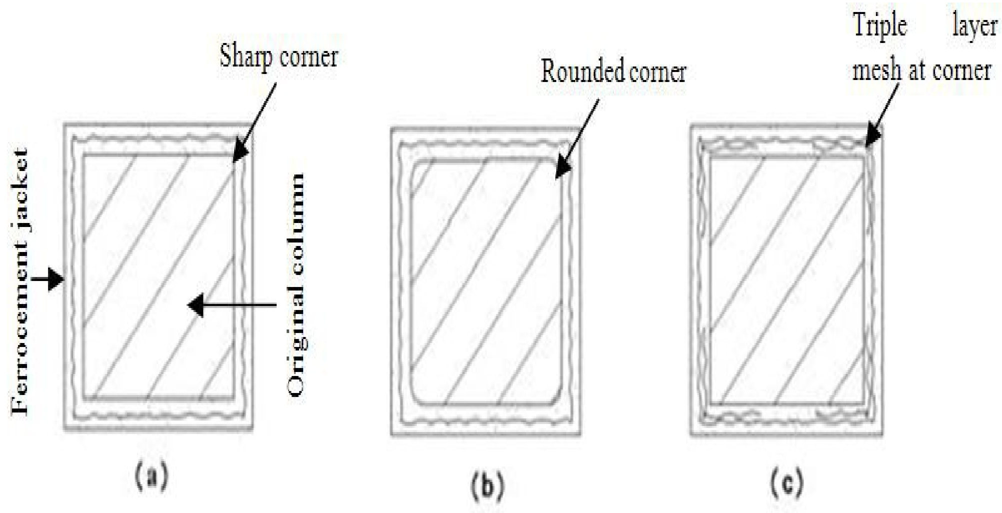


Figure 2. 2: Different ferrocement jacketingtechniques used byAmrul*et al*(2013).

monomers; therefore polymers are categorized as macromolecules because of their big size (Gupta and Kumar, 2015).

Polymer modified concrete (PMC) has been described as cement from hydraulic lime combined with or without aggregates when mixed with dispersed or redispersed organic polymers (ACI 548-3R, 2003). Polymer-modified cement mixtures (PMCs) which include polymer Portland cement concrete (PPCCs) and latex-modified concrete (LMCs) have been used interchangeably. Mortars and concretes modified by polymer have a monumental co-matrix which homogenizes the matrix of the organic polymer and cement gel. The features of polymer-modified mortar and concrete are characterized by such a co- matrix. In constructions altered with latexes, re-dispersible polymer powders and water- soluble polymers, water from hydration of cement contributes to the creation of films or membranes (Hirde and Omprakash, 2016).

Polymer alteration supports concrete modification in two respects, first by reducing the frequency and magnitude of moisture movement by stopping the opening of chambers during hydration generated by voids. Secondly, it also helps in resisting propagation of microcracks when voids occur. The structure is such that the micropores and voids that usually occur in hardened Portland cement matrix are partly filled with the polymer film that develops all through cement hardening. This film is the reason for the decreased permeability and water absorption of the mixture (ACI 548). The latex modification of cement mortar and concrete is controlled by both cement hydration and polymer film formation procedures in their binder stage. Hydration of cement generally comes before the creation of polymer film in the matrix. Both the hydration of cement and the creation of polymer film create a co-matrix stage in due course. A co-matrix stage composed of cement gel and polymer films is generally believed to be established as a binder. The cement interfacial layer hydrates with a large amount of polymer droplets on the aggregates and cement substrates. As a result, in order to understand the composite process of latex-modified constructions, both polymer particle dispersion and polymer film formation are crucial (Ohama, 1995).

The countless breakthrough achieved by modifying concrete structures with distinct types of polymer to address the difficulties of using unmodified concrete have been reported with many beneficial results. The impact of the utilization of polymer modified mortar (PMM) in managing cracks in reinforced concrete beams by subjecting an unmodified beam to excessive loading until crack occurred thereafter a PMM was applied on the cracks and tested again was reported by Ahmad *et. al*.,(2014). The result showed an improved strength quality in its load bearing capacity.

When used as a reinforcing agent, the polymer modified alkali treated jute fibre was observed to significantly enhance the mass, volume, density water absorption, tensile and compressive strength of mortars from cement when blended with other binders. The mortar workability was discovered to improve steadily, the mortar density improved and both water absorption and obvious porosity decreased rapidly (Sumit *et. al.,* 2013). Mahyuddin and Amin (2012) also had a similar result.

Siddiqi *et. al*., (2013) evaluated the physical and compressive strength of polymer altered concrete and observed that at early age of curing these properties were poor but at 28 days of curing there was a tremendous change and improvement in both properties. Rajkumar and Vidivelli (2010) studied the mechanical characteristics of ferrocement modified with polymer by varying the amount of mesh strengthening and the test findings confirmed that modified material laminates could be utilized to considerably boost the flexural ability of beams from reinforced concrete, with effectiveness varying based on the factors tested. Scott and Nathaniel (2013) developed a thin shell ferrocement roof by modifying the mortar with latex which is readily available in paints. Mechanical analysis were performed on some samples to determine the compressive strength, flexural, shear strength and bending load, all these parameters yielded a better performance in resistance to imposed loading when compared with the control sample without any modification.

2.5.1 Types of Polymer Modifications

2.5.1.1 Modification with Redispersible Polymer Powders

All-purpose polymers are added as an aqueous dispersion to the fresh mix of matrix. Redispersible polymer powders are usually produced through a spray drying process from ordinary polymer dispersions (Walters, 1992 and Walters, 1993). During dry mixing, the polymer powders are introduced, followed by mixing in wet form. Re-emulsification of the redispersible polymer powders take place during the moist mixing leading to a stable dispersion eventually. A general analogous behaviour and comparable characteristics are observed after this as in the case of polymer dispersions. The redispersible polymer powders give some convenience, storage and handling benefits, but may be offset by greater expenses or slightly reduced efficiency (Knapen *et. al*., 2006).

Redispersible powders are thermoplastics and form films on distinct substrates with elevated tensile strength and adhesion strength. They function as a second mortar binder in conjunction with inorganic cement. Both cement and polymer are their corresponding advantages. The pronounced rise in mortar adhesion strength on distinct substrates is the primary reason for their extensive use in building systems. They also have long-term outdoor and indoor exposure efficiency (Joachim and Otmar, 2001). Dry blends are made from powdered form of the cement modifiers in order to improve procedures of processing and to avoid errors in mixing. The powdered cement modifiers are often used to produce pre- packaged products for floor preparing, such as decorative wall coverings, tile adhesives and filling compounds (Afridi *et. al.,* 2003).

2.5.1.2 Modification with Water-Soluble Polymers

During mixing with water-soluble polymers such as cellulose derivatives and polyvinyl alcohol, small amounts of polymers are introduced as powders or aqueous options to cement mortar and concrete. Due to the surface operation of water-soluble polymers, such a change mainly improves their workability and prevents dry-out occurrences. The "dry-out" prevention is seen in the altered cement mortar and concrete as an increase in the viscosity of the water phase and as a locking effect due to the development of very small and water- impervious film in them. Water-soluble polymers in specific hardly add to the resistance of modified buildings (Knapen and van-Germert, 2006).

By modifying them with water-soluble polymers, Knapen and van-Germert (2015) studied the growth of films from polymer formation in cement mortars. The existence of polymer films or bridges in the reinforced mortar framework was investigated through examinations of mechanical strength, thermal analysis and microstructural investigation. Polymers have been found not only to act as rheological additives, but in some cases polymer bridges have been produced which acts as a link between cracks thereby reducing further propagation.

2.5.1.3 Modification with Liquid Resins

During the alteration with liquid thermosetting resins, considerable amounts of polymerizable low-molecular weight polymers or prepolymers are introduced in a fluid form to cement mortar and concrete. Usually the polymer content of altered mortar and concrete is higher than that of altered latex buildings. In this alteration, in the presence of water, polymerization is initiated to produce a polymer system, and cement hydration occurs simultaneously (Aggarwal *et. al*., 2007). As a result, a phase of co-matrix is created with a network structure of interpenetrating hydrate phases of polymer and cement, and this binds aggregates heavily. As a result, the strength and other properties of modified mortar and concrete are improved in much the same way as those of latex-modified systems.

Cherkezova *et. al*., (2006) performed studies to obtain hydrophilised polymer concrete in anhydrous media. Their outcome showed that the curing and decrease of the strength characteristics at elevated modifier doses is accelerated by a function of modified binders. However, polymer concrete based on modified polyester binder has a plastic nature of failure that guarantees deformability far higher than that of silicate concrete.

2.5.1.4 Modification with Monomers

The idea of replacing cement composites with monomers is approximately the same as altering liquid resin except that it involves combining monomers rather than liquid resins. Significant quantities of monomers are mixed with cement mortar and concrete in such a modification. Both polymerization and cement hydration occur concurrently during or after matrix hardening to produce a monolithic matrix that links aggregates (Martinez-Barrera *et. al*., 2011).

Generally speaking, such a change was not efficient because of the poor features of the altered structures. The causes for this are the cement hydration interference, the alkalis degradation of the cement monomers and the trouble of uniformly dispersing the monomers and other components all through blending. As such monomers are not to be used alone but blended with others in order to overcome these challenges. Some common monomers that are ultimately polymerized in situ for concrete impregnation are methyl methacrylate, glycerol sodium, methacrylate-styrene and urethane methacrylate. Valore and Naus (1976) reported tests on polymer concrete made from combinations of grid, flexible and low shrinkage polyester resins. In their tests, the unsaturated polyester resin containing styrene monomers in amounts of 20 to 40 percent by weight. Using the highest volume of 9.5 mm as the aggregate, the findings showed that the concrete's compressive strength varied from 71 to 121 MPa and varied from 10 to 20 MPa for its tensile strength. This translates to an average performance from the monomer when compared with established ones such as styrene butadiene that had been previously used.

2.6 Paint As an Emulsion Based Polymer for Concrete Modification

Pigments, binders, solvents and additives form a standard latex paint. The part of the paint that is responsible for the film development as it dries is the binders and it changes the gloss, covering flexibility and durability. Some of the popular but expensive polymers in use include polyurethanes, polyesters, and acrylics; the binder in paint is a worthy substitute for these costly polymers to alter concrete.

The important chemical components of paints have features very similar to polymer admixtures which are chemical additives used to improve cement and concrete materials to produce composite materials with superior resistance (Christopher, 2007). Paint is made up of numerous types of small particles, which ranges from 0.09 to 11μ m and is classed as fine and ultra fine materials. Adding fine particles and applying particle packing theory enables a concrete producer to use poorly formed or fine sand and aggregates that are inadequately graded at the same time still creating user-friendly concrete with improved workability. This enhanced workability is the product of inclusion of fine particles into the blend.

A study revealed that a high performance concrete would be created by including huge quantities of ultrafine fillers with tiny quantities of cement, this would also reduce costs by restricting the cement quantity used in the mix (Lagerblad and Vogt, 2003). The types of fillers normally used in self compacting concrete (SCC) are less than 150 μm in size. However, it is now feasible to include big quantities of particles lower than 10 μm owing to the latest advancement of very efficient superplasticizers. These particles are called ultrafillers, which boost concrete strength and behave as a substitute for cement. Lagerblad and Vogt (2003) discovered that up to 40% of cement can be replaced and comparable resistance can still be obtained.

When the cement was replaced, the optimum effect was achieved, but the same cement/water ratio was maintained. The fillers improved the mix's workability as a consequence. The inclusion of mild fillers also boosted the hydration of cement, with the fineness of the pace decreasing.

Emulsion latex paints are commonly accessible in most markets in Nigeria and it is inexpensive and, most essentially, being water based paints which typify that they can be readily mixed with hydraulic cement. Generally, it does not require a non-foam additive as reported by Scott and Nathaniel (2013).

Most published researches on use of paint as concrete admixture had been focused on waste paints and not virgin paints because these waste paints are prominent feature of most dumpsites in the developed nations where the researches took place. These waste paints are mostly from expired products from factories and those from construction sites with no further use.

However in Nigeria or any other country in Africa, landfill or dump site in which latex coating wastes might be discovered is non-existing because every ounce of the paints generated by these industrial sectors are used up while the paints are used completely by customers of these goods, therefore the accessibility of waste from surface coatings is extremely unlikely.

There is limited accessibility of polymers in either powder or dispersion form to most people in this region of the globe because the transaction involved the use of foreign exchange before purchase and supply to the locations could be done, making them costly and beyond the reach of ordinary men who may want to use them for their elevated resistance value. However, with the use of virgin paints, the desired high strength concrete can be achieved. It has been confirmed that there is no difference in strength properties with the use of either a virgin or waste paints in cementitious materials as reported by Nehdi and Sumner (2003) as both had the similar mechanical properties after tests had been concluded. Varieties of paint constituents are used to produce it, these are outlined below:

2.6.1 Primary constituents of paints

The constituents of paints are:

i. Polymers: Latex paint comprises mainly of polymers and therefore it is the major substance in its manufacturing. This substance supports and then binds the remaining components such as the extenders and pigments together and provides the continuing film forming component of the coating. Emulsion polymers are made up of water, monomers and surfactants and it is the domineering component of paints.

ii. Surfactants: A surfactant is a substance which reduces the liquid surface tension. Surfactants are chemicals that have two separate polarity and solubility elements in their molecules. The size and proportions of the molecule's two components vary among applications.

iii. Control for Foaming: Foaming is regulated by the active antifoams or defoamers in paint, the foam is an undesired surfactant product. These two substances are not the same in the way they work, anti-foam prevents foam from building up, while defoamers cause foam that has already developed to collapse. These two parts are present in paint as paint foaming during application is not appropriate.

iv. Titanium dioxide: As the only non-toxic and easily available pigment (other than zinc oxide), it is the primary white pigment used by the paint industry. It is a transparent particle, yet it looks white owing to the small particle size that allows light to be spread backwards, and thus the eye receives the full light spectrum. It was expected that titanium dioxide would not have an important chemical effect on cement.

v. Thickeners: It is responsible in painting for regulation of consistency of paints and ensures that within the period of storage and application, the workability is maintained (Nasser et. al., 2012).

2.7 Structural Components of a Typical Building

A typical building has two basic parts which are the sub-structure or foundation and the super-structure.

The part of the building that is directly beneath the ground level is known as sub-structure of foundation. It usually transfers the load from the super-structure to the ground. It is the part of the building which is in actual contact with the ground to which loads are transmitted.

Super-structure is that portion of the building that is situated above ground level and serves the purpose of its intended use (Builder, 2017). A building has the following components:

2.7.1 Wall

Wall is an upright structure of masonry, wood, plaster, or other building material that serves to enclose, divide, or defend an environment, particularly a vertical construction that forms a building's inner or outer siding. The purpose of walls is to sustain roofs, floors and ceilings, enclose a room as part of the building envelope, along with a roof to form houses, and provide shelter and safety. Wall construction falls into two fundamental classifications: framed walls or mass walls. The load is transmitted to the base through posts, pillars or studs in framed walls. Framed walls most often have three or more distinct parts: structural elements, insulation, and finishing elements or surfaces (such as drywall or panelling). Mass walls are made of strong material including masonry, concrete including slip form stone masonry, log building, cordwood construction, adobe, rammed earth, cob, earth bag construction, bottles, tin cans, straw-bale construction, and ice (Wiki, 2017b).

Masonry walls are of two kinds, structural walls and rain screen veneer walls. Single wythe concrete block or clay brick walls are the most common structural masonry walls. Each sort provides distinct performance possibilities in terms of climatic variables, fire, thermal, sound and seismic resistance, and building and maintenance costs. In addition, each wall system will have intrinsic aesthetic features. Additional treatments or finishes may be added to each of these wall systems to further develop them (Masonry, 2016).

2.7.2 Roof

Roof is known as part of a building system and it is the covering on the highest part of a building or shelter that gives protection from weather, notably rain but also heat, wind and sunlight. The term also includes the framing or structure that promotes the covering. The features of a roof depend on the function of the building it includes, the available roofing materials and local construction traditions and broader ideas of architectural design and practice, and may also be regulated by local or national legislation. In most countries a roof protects primarily against rain (Wiki, 2017c). An essential component of a dwelling, the roof is critical to shelter, thermal comfort, privacy, and, in some locations, satisfying other needs-for a status symbol, a refuge from floodwaters, a sleeping area, a water-collection system, a storage area, a food- and clothing-drying area.

Usually, low-cost residential roofing in developing nations is not the result of any structured construction industry or method. Instead, it is built using rudimentary procedures and materials with local self-help labour. Most roofs made of low-cost, native materials such as thatch or unfired clay lack durability and can be harmful to health and security. These materials are often subject to decline caused by moisture; they harbour vermin and insects and are particularly hazardous during fires, windstorms, earthquakes and other disasters.

2.7.3 Columns

A column can be described as a vertical structural member intended to convey a compressive load. A column transmits the load to the foundation from the ceiling or roof slab and beam, including its own weight. It should therefore be noticed that a column failure results in the collapse of the entire structure. In the modern construction industry, columns are mostly constructed by concrete; apart from that materials such as wood, steel, fibre- reinforced polymer, cellular PVC, and aluminium too are been used.

Types of Columns

Columns can be categorized based on their form, slenderness ratio, load type and lateral reinforcement pattern.

(a) Classification based on slenderness ratio: the long column or slender column is larger than the critical buckling length and fails by buckling. Short columns are those that have less length than the critical buckling length and fail by crushing while the intermediate column falls between the two listed kinds.

(b) Based on shape: There are rectangle, square, circular and polygon shaped columns

(c) Based on type of loading: There are axially loaded column, axial load and un-axial bending column and axial load and biaxial bending column

(d) Based on pattern of lateral reinforcement: There are tied columns and spiral columns (Builders, 2017).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Collection and Preparation of Test Materials

The materials used for the production of polymer modified bamboo reinforced cement composites were bamboo, fine and coarse aggregates, ordinary Portland cement, potable water, acrylic emulsion, chicken wire mesh, steel and asphalt emulsion.

3.1.1 Bamboo

Bamboo (*Bambusa vulgaris*) samples with an average age of 3 years were harvested from Omu-Aran, Kwara State, Nigeria at the location having a Latitude of 8^o 08' 18.85" N and Longitude of 5^o 06' 9.36 E". These were scientifically identified at the Department of Biology, Landmark University, Omu-Aran, Nigeria. Forty numbers of bamboo culms were cut 0.75 meters from the base. The lengths of the bamboo ranged from 3.4 to 5.7 metres with 22 nodal areas and the average diameters were 89.5mm, 85.4mm and 72.9mm at the base, middle and top regions respectively. They were sun-dried to 8% moisture content from an initial value of 25%. The culms were then reduced to smaller strip sizes of 450 mm length (Plate 3.1). The billets were hammer milled to 2.5 mm at the commercial farm in the University and sieved with 2.00 mm (B.S. 3310) sieve. The fibres that were retained on the 2.0mm sieve were of 13.40 mm and 0.62 mm in length and thickness respectively.

Soaking of the fibre in 10% concentration of NaOH (sodium hydroxide) solution was done for 24 hours in order to remove lignin, a major component of the cellulose within natural fibre (Oushabi *et al*., 2017), and followed by the washing of the fibres with clean potablewater. This pre-treatment usually reduced the fibre diameter and ultimately improves the aspect ratio (length/diameter) which consequently increases the effective roughened fibre surface area and improved matrix bonding. Alkaline treatment generally leads toenhanced thermal and mechanical characteristics of the cellulose material reinforced cementitious composites (Oushabi *et al*., 2017). The treated fibres were air-dried by spreading on a levelled surface for one week at room temperature with the final moisture content ranging from 2 – 7% as shown in Plate 3.2.

3.1.2 Cement

Portland Limestone Cement (PLC) was bought from the market in Omu-Aran town, Kwara State.

3.1.3 Acrylic Polymer

An acrylic emulsion paint which is also known as Latexes was locally sourced within Omu-Aran metropolis and it conforms with ACI 548-1R-47 standard. These are shown in Plates 3.3.

3.1.4 Sand, water, coarse aggregate

Sharp sand used was obtained from a pile at the Engineering Workshop Complex of Landmark University. This was sieved with 2.0mm sieves (B.S. 3310) to remove impurities and other extraneous materials. The fine aggregates that passed through the 2.0mm sieve were used for the mix. Potable water was sourced from the tap within the Laboratory while coarse aggregate of maximum size of 20mm was used for the mixing. These materials conformed to the BS EN 12620 standards.

3.1.5 Moulds

Three sets of moulds were used. The first set was used for the production of compressive test samples having dimensions of 150 x 150 x 150 mm. The second set of moulds was used for the production of flexural strength test samples having dimensions of 150 x 200 x 600 mm. The third set was a cylindrical mould with a dimension of 150 x 350 mm which was used for the production of split tensile test samples.

3.1.6 Other materials and instruments

Other materials used were: TIANFU DT-1000 Electronic scale, Memmert UF 75 drying oven, Handheld thermometers, Plastic bucket, aluminium pot, string, KADIO KD–1069 stopwatch, Lee- Disc thermal conductivity apparatus, desiccators, digital vernier callipers, voltmeter, ammeter, AC-DC power source, pen-shaped hygro–thermometer (Temperature Range is 0 ± 50°C and humidity range is 20% - 95% RH while the temperature accuracy was ±1°C), thermal waterproof digital thermometer (range is -100 to 1372°C and accuracy is ±0.3°C) and glycerine solution. Super Bond bituminous resin, chicken wire meshes, hand gloves, electric stove, dial gauges and metal stand.

Plate 3. 1: Bamboo strips

Plate 3. 2: Air-dryingoftreated bamboofibres

Plate 3. 3: Acrylicpolymerpaint poured into head pan

3.2 Design and Construction of Multi-Purpose Concrete Vibrating Table

The two main instruments needed for roofing tiles production were the vibrator and mould. These were designed and fabricated before the roof production started. The main purpose of designing the vibrating table were:

For uniform compaction of the mix

- Removal of air voids
- Improvement of strength and durability of product through the closer coagulation of the particles and
- Development of a homogenous, uniform and non-porous composite mortar

A table vibrator of 914.40 x 812.80 x 1524 mm was designed based on the force diagram (Figure 3.1) and electromechanical principle (Figure 3.2) (See Appendix O for the development images). This is a motorized unit consisting of a camshaft driven by a motor. The shaft runs in a double ball bearing. The duration of vibration of the table vibrator is dependent on the concrete stiffness, the structural dimensions, the amount of reinforcement, amplitude of the vibrating mechanism and the frequency of operations (Omoniyi, 2009). The designed vibrating table was based on the modification of the cited author’s design.

3.2.1 Components of multi-purpose concrete vibrating table

i. Spring:A spring is a flexible object mostly utilised to store up mechanical energy. Hardened steel is the major material used in the production of springs. Whenever a compressive force or an extensive force is applied to it, it is usually proportional to the change in length. The constant rate in spring is equivalent to the force changes applied, separated by the spring's change in deflection. Springs were used to keeping contact between the vibrating table.

ii. Cam: The cam mechanism was used for providing the vibrations. A cam alters the motion inputted and this is basically a rotary motion which is reciprocated by the subsequent motion of the trailing pattern.

iii. Bearing: Bearings was used to provide support to the shaft and to allow its rotation smoothly without being dislodged.

iv. Shaft: shaft was connected to the motor and it carried the cams on it. A keyway was provided on the shaft to fix the cams on it.

v. Motor: A motor of 0.5HP power rating was used to drive the shaft. This value was obtained from the design calculations. The shaft of the motor was then connected to the cam.

3.2.2 Technical drawings and design calculations

The detailed drawings of the concrete vibrating table are clearly shown in Figures 3.2, 3.3 and 3.4. The design calculations are shown in Appendix T as well.

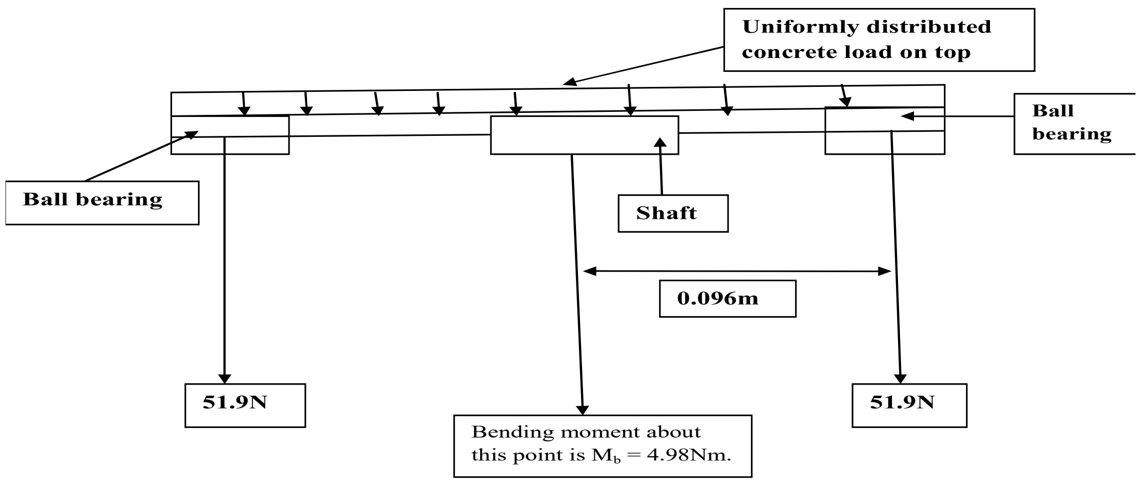


Figure 3. 1: Force diagram of vibrating table

3.2.3 Principle of operation

The mould containing the slurry is placed on the flatbed of the vibrating table. The electric motor (0.5HP power rating) which is attached to the reciprocating rod was switched on. This sets up a series of minimum and maximum displacement (20 – 30mm) of the reciprocating rod from the equilibrium point at the pulley from the electric motor. This was achieved at an amplitude of 0.33±0.05mm and a frequency of 60 Hz based on ASTM D 4253. The rod which is connected to the horizontal shafts with two ball bearings at its ends is displaced vertically upwards and downwards being aided with the four spiral springs that are attached to the frame of the steel bed connected to the shaft. The vibrations in the vertical direction are continuously varied from the maximum level to a minimum level by the shift in the position of the reciprocating rods and the four spiral springs. Once compaction has beenachievedwhich is noticeable by the disappearance of bubbles on the slurry surface, the electric motor with a power rating of 0.5HP is switched off.

3.3 Experimental Mix for thePreliminary Test

The concrete mix used for production was in accordance with ACI 548.3R-03 for polymer-modified concrete (Table 3.1). The preliminary experimental design is shown in Table 3.2. A total of 378 blocks were produced out of which 54 were used for the preliminary experimental mix and tested after 28 days. The remaining 324 specimens were used for the final testing. As shown in Table 3.1, 1:10 mixing ratio of polymer to cement and 1:3 mixing ratio of cement to sand respectively were used for the production of samples in Tables 3.2, 3.3, 3.4 and 3.5 respectively.

3.3.1 Mixing and Moulding of Bamboo Fibre Reinforced Concrete for Initial Test

The following procedures were employed in the production of bamboo fibre composites without polymer inclusion. The constituent materials were batched in proportions determined by experimental design in Table 3.2. The weight of sand needed to fill the mould was determined using batching by weight. The sand of 20.8kg weight was found appropriate and 6.9kg cement was weighed and dry mixed until uniformity was attained. This was based on the 3:1 mixing ratio of sand:cement. Bamboo particles (1.8mm) were dry mixed with sand:cement ratio of 3:1 at 0.5, 1, 1.5, 2.0 and 2.5% based on total constituents weight. Water/cement ratio of 0.58 was added until homogenous mortar was formed. This was placed into 150 x 150 x 150 mm moulds positioned on a level surface which had been previously oiled for easy demoulding. The constituent was compacted uniformly using the standard tampering rod. The wet mix was smoothened with a hand trowel, labelled, covered with polythene sheets and permitted to harden for 1 day before demoulding. Curing was done by placing the samples in water tank having a temperature of 23^oC for 28 days after which water absorption, thickness swelling and compressive test was performed following EN and ASTM standards. The same processes were repeated for all the samples (R to E).

3.4 Final Experimental Mix forTest Materials

Mix design adopted for the final test were categorised into three phases. The first phase dealt with varying the acrylic polymer contents only at 5%, 10%, and 15% of the weight of cement as shown in Table 3.3. Phase two involved constant fibre at 1.5% which is the optimal fibre content obtained after the preliminary studies had been concluded from the initial test and varied polymer contents at 5, 10 and 15% of the weight of cement (Table 3.4). Phase three involves constant acrylic polymers at 10% weight of cement which is the optimal polymer content from phase one and varied fibre contents at 0.5, 1 and 1.5% as shown in Table 3.5. While varied bamboo fibres contents of 0.5 and 1% were blended with varied polymer contents of 5 and 15% as displayed in Table 3.6.

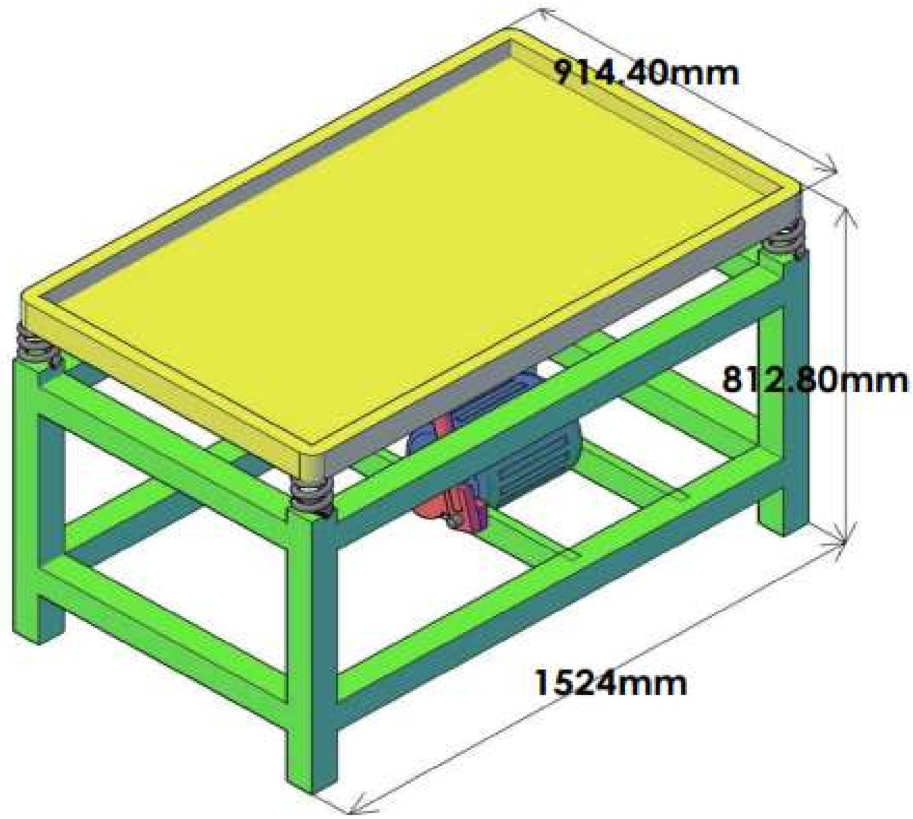


Figure 3. 2: Dimensions of multipurpose concrete vibrating table

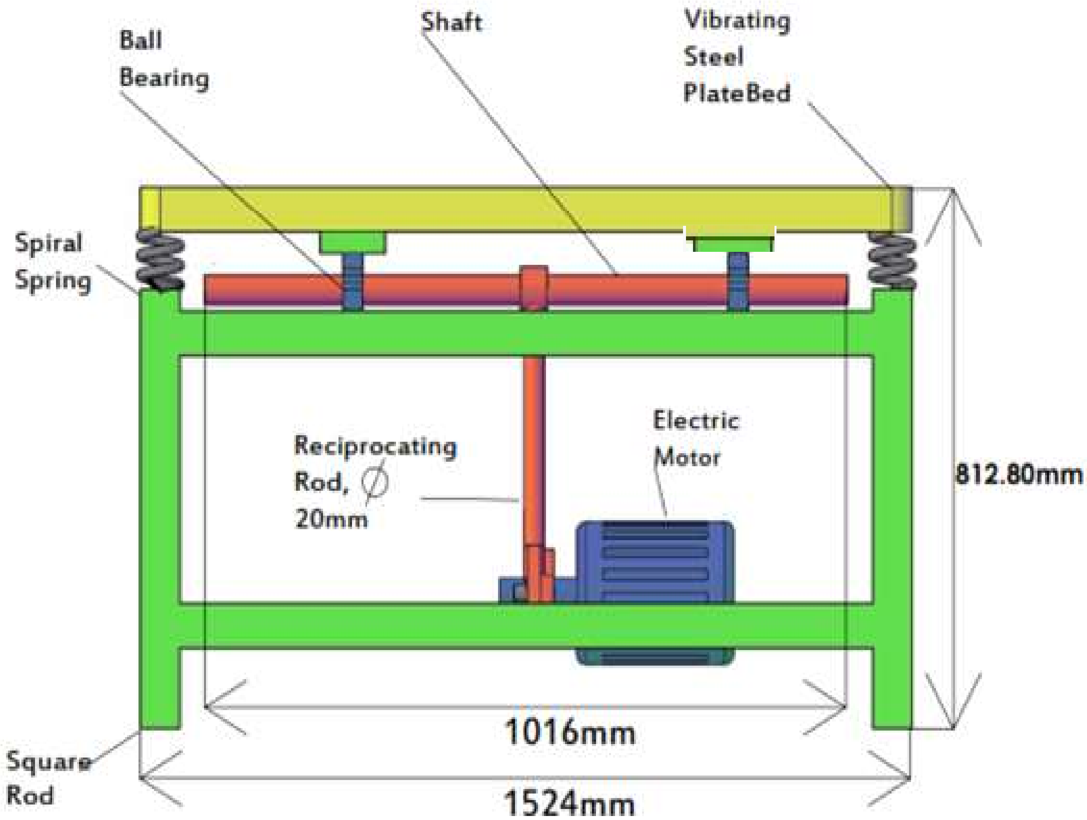


Figure 3. 3: Side view of multipurpose concrete vibrating table

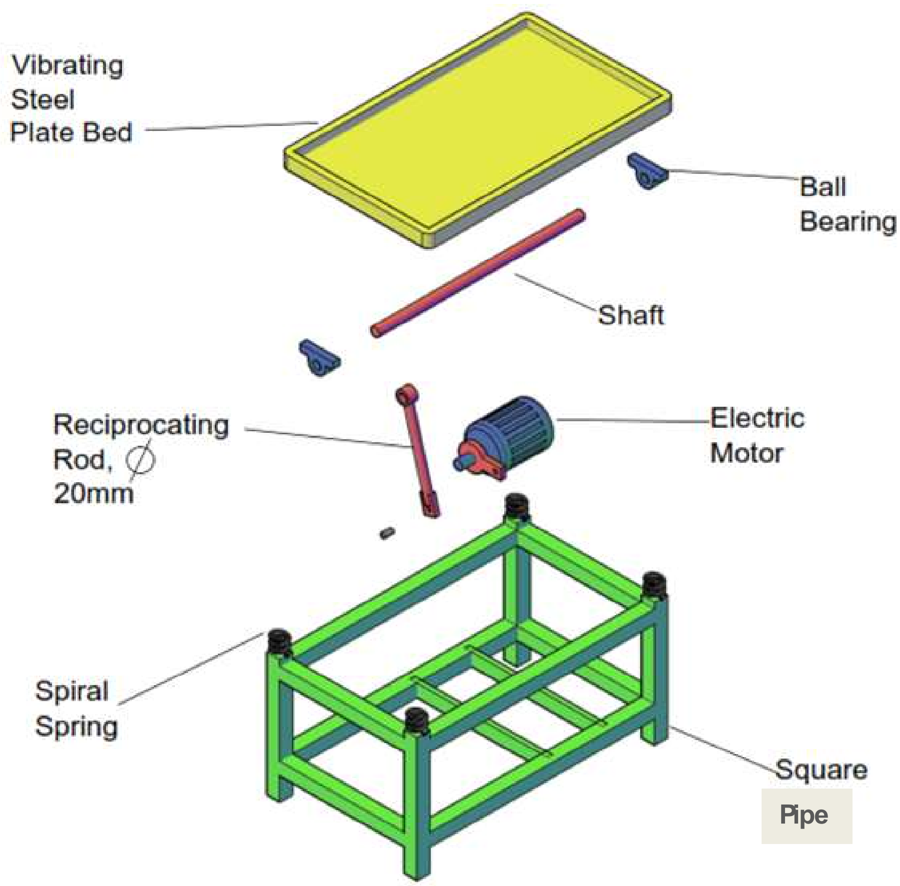


Figure 3. 4: Exploded view of multipurpose concrete vibrating table

Table 3. 1: ACI 548.3R Standard Mix

Ingredients	**Mass (g)**
Sharp sand	300
Portland limestone cement	100
Acrylic latex	10
Aggregate –cement ratio by mass	3.0
Polymer-cement ratio by mass	0.1

Table 3. 2: Effect of bamboo fibre contents

Sample code	Fine sand (kg)	Cement (kg)	Bamboo fibre (%)	Water (kg)	Rep.
P	20.8	6.93	No fibre	7	9
R	20.8	6.93	0.5%	7	9
I	20.8	6.93	1.0%	7	9
N	20.8	6.93	1.5%	7	9
C	20.8	6.93	2.0%	7	9
E	20.8	6.93	2.5%	7	9

Table 3. 3: Effectof polymer contents on the properties of composite

Sample Code	Mix composition (wt of cement)	Sand (kg)	Cement (kg)	Polymer (kg)	Water (kg)	Rep.
CT	Control	50	16.7	0	8.2	27
B	5% polymer	50	16.7	0.835	7.9	27
C	10% polymer	50	16.7	1.67	7.6	27
N	15% polymer	50	16.7	2.5	6.8	27

3.4.1 Production of Brick Specimens

The procedure outlined in Section 3.1 was followed in processing bamboo culms into fibres. Sieving and soaking in NaoH solutions and drying was done in a controlled environment within the Laboratory to moisture content range of 7 to 10%. Sieve size of 2.00mm was used for the bamboo fibres and the fibre particle sizes that passed through had 23.74 and 2.31mm as the maximum length and thickness, as well as 5.09 and 1.25 mm as the minimum length and thickness. Sharp sand passing through 1.18mm sieve with all debris and organic wastes removed was used for blending with cement. The binder used was Portland Limestone Cement while water used for mixing was from the University Water system. Acrylic polymer paint was used in place of polymer admixtures utilized for modifying concrete.

The following items were also used; these were six 150 x 150 x 150 mm moulds, six moulds of 150 x 200 x 600 mm beams and nine standard cylindrical sized 350 x 150 mm moulds. The interior of the moulds was greased with used engine oil which was obtained from a Mechanic Workshop for smooth sample demoulding after the production.

Procedures reported in Section 3.2 were used to prepare cement, sand and bamboo fibres used for sample production. However, the inclusion of acrylic polymer paint into the mixture involved calculating the weight of polymer needed for each percentage based on weight of cement. Thereafter the calculated weight of the polymer was measured, poured into a clean plastic container and diluted with a measured amount of water which conforms to the water/cement ratio of 0.58 before it was mixed with the already prepared mixture of cement, sand and bamboo fibres for about 3 minutes. Thereafter, the cement matrix was poured into each mould and compacted with a standard rammer for about 2 minutes to ensure good compaction, it was initially air-cured for 7 days and water cured for the remaining 28, 45 and 60 days at 24 ^{o}C before the mechanical tests were performed. The composite blocks of 324 in number (Plate 3.4 shows the aerial view) were later transported to the Geotechnical Laboratory within the University.

Table 3. 4: Effect of polymer contents at 1.5% fibre on composite properties

Sample Code	**Mix composition**	**Fibre (kg)**	**Sand (kg)**	**Cement (kg)**	**Polymer(kg)**	**Water (kg)**	**Rep.**
CT	Control	0	50	16.7	0	7	27
O	5%polymer, 1.5% fibre,	1.1	50	16.7	0.835	6.4	27
R	10%polymer, 1.5% fibre	1.1	50	16.7	1.67	6.1	27
Y	15%polymer, 1.5% fibre	1.1	30	16.7	2.5	5.9	27

Table 3. 5: Effect of bamboo fibre contents at constant polymer on composite properties

Sample Code	Mix composition	Polymer (kg)	Sand(kg)	Cement (kg)	Fibre (kg)	Water (kg)	Rep.
C	Control (10%polymer)	1.67	50	16.7	0	6.1	27
D	10%polymer, 0.5% fibre	1.67	50	16.7	0.34	6.1	27
A	10%polymer, 1.0% fibre	1.67	50	16.7	0.68	6.1	27
R	10%polymer, 1.5% fibre	1.67	50	16.7	1.02	6.1	27

Table 3. 6: Effect of varied polymerand bamboo fibre contents on composite properties

Sample Code	Mix composition	Polymer (kg)	Sand (kg)	Cement (kg)	Fibre (kg)	Water (kg)	Rep.
X	0.5% fibre, 5%polymer	0.835	50	16.7	0.34	6.1	27
K	0.5% fibre, 15%polymer	2.50	50	16.7	0.34	6.1	27
G	1.0% fibre, 5%polymer	0.835	50	16.7	0.68	6.1	27
E	1.0% fibre, 15%polymer	2.50	50	16.7	0.68	6.1	27

3.5 Physical Properties of Bamboo Reinforced Polymer Modified Cement BondedComposites (AEPMBRC)

3.5.1 Density, Water Absorption and Porosity

Twenty-four samples having 10 mm width and 22 mm radius were formed and 28 days water curing was done for these particular tests. The test conforms to ASTM C 642- 06 standards in which water absorption; voids and density of the AEPMBRC were evaluated.The initial mass of each sample was determined and later placed into the Memmert oven to dry at a temperature of 105 ^{o}C for 24 hours. After removing the AEPMBRC samples, they were transferred into a dessicator and allowed to cool to a temperature of 24 ^{o}C.

Thereafter, the mass was determined and it was discovered that value of the initial mass does not agree with the second mass with a wide difference, the samples were then transferred back into the oven for another drying at the same temperature for 24 hours. The same procedure was repeated and the same wide margin of difference in mass was observed which resulted into another series of drying a whole day, subsequently the specimens were removed, allowed to cool, the mass determined and the difference observed was less than 0.5% of the former and this showed that the samples are now dried as stipulated by the ASTM C 642- 06 standard, this new weight was tabulated as A.

Saturated masses after soaking were obtained by immersing the entire samples into a plastic transparent bucket and covered with tap water for 48 hours at 24 ^{o}C thereafter, two successive mass reading after drying the samples with dry towel were taken at intervals of 24 hours and the recorded difference was wide. They were immersed again into the bucket for another 7 hours until the change in mass was less than 0.5% of the last reading. This final mass was designated as B.

The samples were transferred into an aluminium pot, covered with tap water and boiled for 5hours. It was permitted to cool for 15 hours at ambient temperature to a final temperature of 24 ^{o}C, thereafter the moisture on the surface was cleaned using a dry cloth and the mass obtained, this was recorded as C which is the mass of saturation after boiling. Each sample was suspended in water to determine its mass by tying a copper wire around it and attached this to a horizontally positioned plastic stick that was placed across a transparent receptacle containing water. The initial mass of this assembly without the samples were noted, then the samples were attached and the difference gives the mass of each sample that was suspended in water (Plate 3.5). This mass was denoted as D which is the immersed apparent mass.

The following calculations weremadebased on theASTMC 642-06 adopted:

1. Absorption after immersion (%) = $\frac{(B-A)}{A}$ X 100……………………….(3.17)
2. Absorption after immersion and boiling (%) = $\frac{(C-A)}{A}$ X 100…………..(3.18)
3. Bulk density, Dry = $\frac{A}{(C-D)}$ X ρ……………………………………..(3.19)
4. Apparent density = $\frac{A}{(A-D)}$ X ρ……………………………………........(3.20)
5. Bulk density after immersion = $\frac{B}{(C-D)}$ X ρ…………………………......(3.21)
6. Voids (%) = $\frac{C-A}{C-D}$ X 100…………………………………………......(3.22)

   Where A = mass of oven dried sample in air, g

   B = weight of surface dry sample in air after immersion, g

   C = weight of surface dry sample in air after immersion and boiling, g

   D = apparent weight of sample in water after immersion and boiling, g

   ρ = density of water = 1 g/cm^3 (constant temperature is assumed)

7. Bulk density after immersion and boiling = $\frac{C}{(C-D)}$ X ρ……………….(3.23)

3.6 Thermal Properties Test

3.6.1 Thermal Conductivity

Eight AEPMBRC samples comprising of C, D, A, R, B, O, N and Y (Tables 3.1 - 3.5) of about 7.5 mm thickness and 43.7 mm diameter were produced. These were obtained after the reduction of the initial samples of the same diameter from 15 to 7.5 mm thickness for insertion into the thermal conductivity apparatus. The samples were placed in the Memmert oven for drying and the temperature was set at 150 ^{o}C for

Plate 3. 4: Aerial view ofAEPMBRC blocks.

Plate 3. 5: Suspendedassemblywith sample

24 hours. Then the difference in weight stayed the same after 2 consecutive weights and after placing the samples in a moisture analyzer a standardized moisture content of 0.8 was obtained. The sample surfaces have been smoothed to guarantee excellent thermal contact with the surfaces of the brass disks.

The deviceused for thermal conductivity evaluation is known as Lee's Disc apparatus (Plate 3.6) which operates on the basis of complete linear parallel disc method. The device was obtained from the Department of Agricultural Engineering, FUTA but the actual experiment was conducted in Crop Processing and Storage Laboratory, Landmark University. The apparatus consists of 3 brass discs with letters A, B and C engraved on them, each has holes bored on them to accommodate liquid glass thermometers which are used alongside with glycerine solution to prevent breakage during temperature readings. The device also has an attached 6W electrical plate heater of the same diameter as the brass plates. Each of the AEPMBRC samples was then sandwiched one after the other between plates' A and B, the heating component was positioned between discs' B and C thereafter the clamp screw was tightened firmly to hold all the assembly together rigidly. The apparatus was connected to a 55 ohms resistor, a 50V capacity voltmeter was then connected in parallel to the resistor, a 30A capacity ammeter was later connected in series to these setups, a key was placed between them and finally, a 50 Volts variable AC-DC power was connected to close the connections as seen in Figure 3.5 and Plate 3.6. The entire set up was positioned in an enclosed space to minimise the effects of draught and a pen-shaped hygro-thermometer was placed fairly close to the apparatus within the enclosure to record the room temperature.

At the beginning of each test, the power from the variable AC-DC was turned to 30 Volts and the whole assembly was allowed to heat up for about 2 hours until the desired average temperature readings after 3 successive readings were stable. Thereafter, readings were taken every 15 minutes using a stopwatch as the timer and it was observed at the first reading that 2 of the glass-liquid thermometers were faulty and gave wrong values which necessitated the switch to using the digital thermal waterproof thermometer which gave more accurate temperature readings. It takes about 10 minutes to take each temperature readings to allow a stable equilibrium to within +0.1 or – 0.1 temperature value for accuracy purposes.

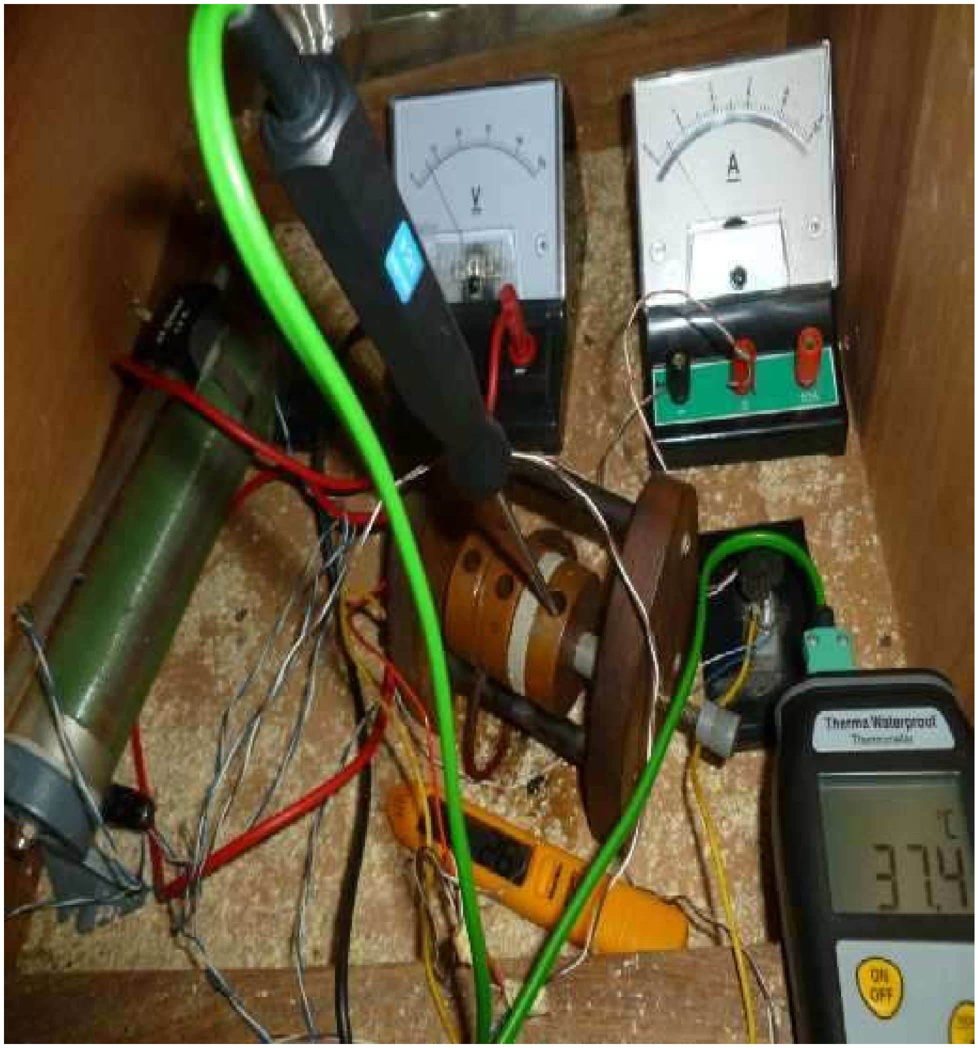


Plate 3. 6: Lee's Discthermal conductivityarrangement

The thermal conductivity (λ), was obtained after using the thickness (d) and radius (r) of each sample from equation 3.24 below:

$$\lambda = \frac{e.d}{2\pi r^2 (T_B - T_A)} [a_s \frac{T_A + T_B}{2} + 2 a_A T_A] \ldots\ldots (3.24)$$

therefore e is gotten through equation 3.25:

$$e = \frac{V.I}{[a_A T_A + a_s \frac{T_A + T_B}{2} + a_h \frac{T_B + T_C}{2} + a_B T_B + a_C T_C]} \ldots\ldots (3.25)$$

Where $a_A = a_C = \pi r^2 + 2\pi r l_d$, …………………………………(3.26)

$a_B = 2\pi r l_d$, $\alpha_s = 2\pi r l_s$ and $a_h = 2\pi r l_h$.

l_d = disc thickness, l_s = sample thickness and l_h = heater thickness.

a_A, a_B, a_C, a_s and a_h = A, B, C discs' and electric heater surface area that were exposed.

T_A , T_B and T_C = discs' A, B and C temperatures (gotten after subtraction from the environment temperature to obtain this value) (Oluyamo, 2012)..

The unit of measurement of thermal conductivity is W/mK.

3.6.2 Thermal Resistance

Thermal resistance is given as:

$$R = \frac{l}{\lambda} \ldots\ldots (3.27)$$

Where R = m^2K/W, thermal resistance

l = material thickness (m) and

λ = conductivity (W/m.K)

3.6.3 Thermal Transmittance

Thethermaltransmittanceisderivedfrom the inverseofthesum of thermal resistanceof the particular material under consideration. It is also called the U-value which is the evaluationofthequantity ofheatthatislostby aspecifiedthickness ofthespecificmaterial, butinvolvesthethreemainformsinwhichthermallosshappens– radiation, convection and conduction.

It is the reciprocal of the R-Value added to convection and radiation heat losses (negligible if conducted in an enclosure), as follows:

$$U = \frac{1}{R} + \text{convection heat losses} + \text{radiation heat losses} \ldots\ldots (3.28)$$

3.7 Micro-structural Analysis

These analyses involved conducting Energy-Dispersive x-ray Spectroscopy (EDS) and Scanning Electron Microscope (SEM) using the Phenom ProX SEM model MVE0224651193 operated at 15Kev using X-ray analysis to determine the samples internal network arrangement physically while the EDS gives their elemental and chemical compositions. The analyses were done in the Mechanical Engineering Department, Covenant University, Ota, Ogun State. SEM/EDS analysis for the characterization of the bamboo reinforced acrylic emulsion polymer-modified mortars samples were carried out at the age of 28 days.

The AEPMBRC samples were carefully placed on aluminium stubs using an adhesive that is conductive. Stubs were positioned on the platform designated as coater place. Gold using Quorum sputter coater was applied on specimens. Subsequent to coating, the AEPMBRC specimens were prepared for analysis in the scanning electron microscope by positioning individual samples in a conventional sample holder and the micrograph images were captured in accordance with the equipment's manual.

3.8 DeterminationofMechanicalPropertiesoftheComposites

The followingmechanical properties ofthecomposites weretested:

3.8.1. CompressiveStrengthTestofAEPMBRC

Theuniversalcrushingdeviceofmodel50-C9083with a capacity of 10 tonneswasusedforthistest.Thetest wasperformedfollowingBSEN 12390(2012) standard.The proceduresusedfor conductingthetest are asfollows:

i. The cubewas centrallyplaced on the surface of the platen with roughened surface facing the perpendiculardirectionoftheplaten.

ii. Theupperplatenwaspushed downwardson tothecubetoensureproper balancingbyslowly turning of theupper platenwhen lowered unto the cube surface.

iii. Thetest machinewas seton the correctloadingand thepointer was zero.

iv. Theloading rateof10mm/minwas graduallyapplied continuously.

v. Themaximumforceon thesample at failure wasrecorded (Plate 3.7).

Equation 3.21 gives the compressive value of each specimen.

$$F_C = \frac{maximum\ load}{cross\text{-}sectiona\ \ area\ of\ specimen} \quad \text{………………………… (3.21)}$$

Where F_C= compressive strength (N/mm^2) while the peak load that the sample sustained is P_{max} (N) and the sectional area is given by A (mm^2).

3.8.2 SplitTestofAEPMBRC

SplittingtensilewasperformedinaccordancetoASTMC496-04inwhich150x350 mm cylindricalshaped specimensweretested.The followingprocedurewas followed:

i. Thediameterwas determined usingthedigital vernier caliperto nearest 0.01mm ii. Diametrical lines weredrawn on oppositesidesalongthelength ofthesample.

iii.Thespan was measured using asteel measuring line

iv.A strip ofmetal was placed alongthecentre ofthebottom blockbearing.

v. Sampleswerepositionedonastripandalignedwith goal of making the markedlines located at ends ofthespecimento be centred and vertical on top ofthemetal piece.

vi.Anothermetalpiecewaspositionedalong the lengthofthecylinder and thereafterpositioned on centered marked lines at the cylinder ends.

vii.Itwasensuredtheuppermetalwasdirectedbeneaththecentreofpowerof the spherical block bearing.

viii. Increasing load at the rateof1.5MPa/minute wasapplied without shock.

ix.Thepeakappliedloadatfailuredisplayedbytheequipmentwas recorded

Thesplitstrengthofeachspecimen wascalculatedusingthe equation:

$$T = \frac{2P}{\pi l} \quad \text{……………………………………..……….. (3.22)}$$

Where T =splittingtensilestrength (MPa),

P=maximumload applied(kN)

l =length

d =diameter ofthespecimen

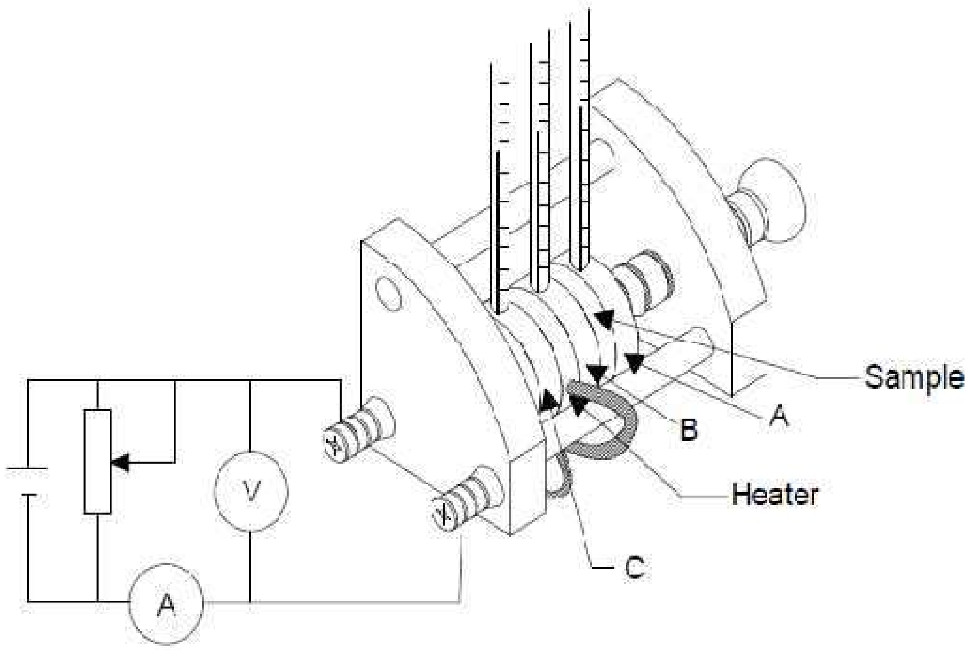


Figure 3. 5: Laboratorysetup ofLee's disc for measuring thermal conductivity

(Source:Oluyamo 2012).

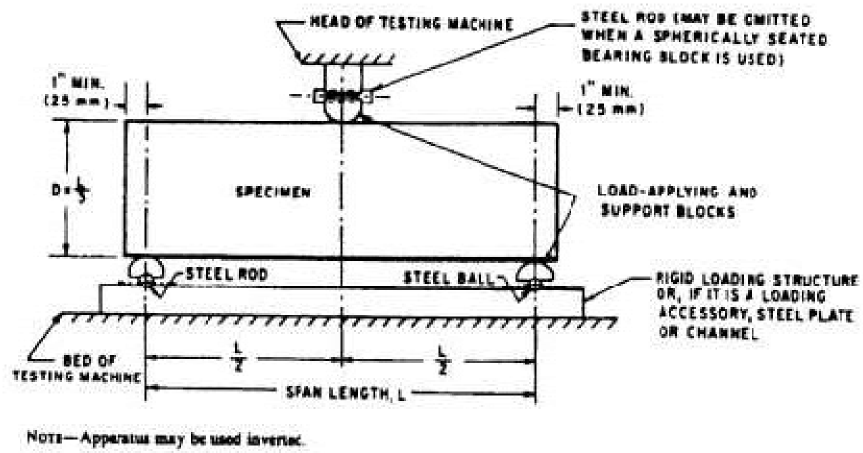


Figure 3. 6: Centerpointloadingsystem forflexural test

(Source:WSDOTTestMethodNo.802:FlexuralStrengthMethodofTests forConcrete withSimpleBeam With Center-PointLoading)

3.8.3 Flexural StrengthTestofAEPMBRC

These testswereconductedaccordingtoBSEN12390(2009)using beams with centerpoint loading arrangement as shown in Figure3.6.

The followingprocedures werefollowed:

i. Thespan of600mmwas used for placing the sample.

ii. 25mmwasmarkedatbothendsofthebeamforpositioningoftwobottom- placed rollersupport.

iii. Themiddleofthebeam was markedforpositioningofthecentresupport

iv. Thesample was placedin device for the testwith thetop surfacefacingme

v. Increasingloading speed of15MPa/minutewas usedwithout shock.

Equation 3.23 gives the value:

$$f_b = \frac{P\,L}{bd^2} \quad \text{...}(3.23)$$

Where rupture modulus is the same asflexural strength (N/mm^2)

P,L,banddaredefinedastheultimateload(N),supportingrollerdistance(mm),width ofbeam (mm) anddepth ofbeam (mm).

3.9 Development of Bamboo Strip Reinforced Acrylic Polymer Modified Ferrocement Roof Panels

3.9.1. Manufacturing of the wooden mould

Six numbers of 50 x 50 mm wooden planks were cut to sizes of 5 feet each to cover the span of the mould. Two semi-circular pieces of wood were carved out using the carving machine in the wood workshop to form the semi-circular top and half-arcs which is almost straightened out at the ends for both sides of the mould and this gave the desired shape for both the head and bottom side of the skeletal frame. These semi-circular shapes are of 609 mm each and it gave the width of the roof to be developed. The 50 x 50 mm planks were then nailed inside the semi-

Plate 3. 7: Samples after compressivetest

-circular head and bottom shapes respectively to form the skeletal frame, it was ensured that the planks flushed with the sides of the frame.

Thereafter, two plywood pieces were nailed to the surface of the frame to cover the entire roof formwork. Another wooden template was also designed which was used to flush the wooden mould after the ferrocement materials had been laid on it thereby removing excess mortars not needed for the roof formation. It also serves to provide uniform thickness for the surface area of the roof. For easy demoulding and to prevent quick drying after casting, polyethene nylon was used to cover the surface of the wooden mould.

3.9.2. Preparation of the constituent materials

Chicken wire mesh was flattened with a hammer and then rolled on the floor to free it from being entangled. The desired length of 1828 mm and breadth of 609 mm were cut out of the roll using scissors. The cut-out section was further straightened on the floor by applying weight on them by placing objects which would hinder it from folding again. Sections of bamboo culms already obtained earlier were further split using a knife to reduce its thickness to 5mm, thereafter; the thickness was further reduced by using a handheld planning device to a thickness of 2 mm. Three strips of bamboos were used for each roof. A concrete mix ratio of 3:1 of sand:cement was adopted, thoroughly mixed until a homogenous appearance was obtained after this acrylic emulsion polymer of 10% weight of cement was added after diluting with water until the desired workability was achieved.

3.9.3. Production of bamboo strip reinforced polymer modified ferrocement roof

The polythene nylon was first placed on the wooden mould and carefully spread to ensure complete covering of the mould surface. After this, the already measured and cut out a portion of the chicken wire mesh was placed on the mould and positioned so that it did not extend beyond the sides of the mould. One of the bamboo strips was positioned at the upper part of the mould and tied with copper wire to the chicken mesh; the other two bamboo strips were placed at the bottom sides of the chicken mesh and tied as well with copper wires until they were held firmly in place. The prepared mortar was then worked through the openings on the chicken wire mesh until the entire surface and mesh arrangement were completely encapsulated in them. The entire constituents and formwork was placed on the developed vibrating table and vibrated for about 2 minutes after this the surface was smoothened with an hand trowel. The entire framework was transferred to a worktable where the protruding bamboo culms were trimmed to size and curing was allowed to take place (Plate 3.8). Laboratory curing was done for 24 hours then 3 litres of water was sprinkled on it at 3 hours intervals to reduce rapid hydration of the cement which might lead to cracking of the hardened roof. After 48 hours of air curing, it was demoulded and further air-cured for 28 days at the Wood workshop, University of Ibadan.

3.9.4 Installation of Composite Ferrocement Roof Panel on Constructed Wooden Frame

A piece of land was acquired, set-out, marked and pegged with spacing's of 1524 mm on two sides and 1828 mm on the other side were done. The holes were dug to a depth of 1 metre each and four timber poles were erected and the ferrocement roofs installed (Plates 3.9)

One edge was lifted unto the frame while the force was applied to push the other edge of the roof unto the top of the wooden frame. The same process was followed to move the second roof unto the top. It was ensured that the two longer sides of the roof were placed close together to allow concrete to be poured into the formed trough. Masonry nails which are usually the toughest and strongest available nail made from hardened zinc (Designing Buildings Wiki, 2019) were used but it only got to a depth and did not get through, thereafter concrete drilling bit was used to bore holes into it and metal strips were subsequently used to tie it to the truss on top. High strength mortar was prepared and poured into the trough to secure both roofs together.

3.10. Performance of Roof

3.10.1 Edge Cracking and Delamination Study by Visual Inspection

The method described by Fiorelli *et. al*., (2014) was modified and used for this study. The roofs were exposed to natural weathering for 24 months (February 2017 – February 2019). During the installation process, the roofs were oriented in the North-South direction for the maximum incidence of solar radiation. This study was performed utilizing visual inspection reported by Fiorelli *et. al*., (2014) in order to observe the magnitude and defect numbers detected on the lateral face.

The lateral surfaces of the roofs were splited into eight (8) sections for easy quantification and recognition of incidence of delamination and cracks at the edges. Four sections were marked at the North portion and labelled as N1, N2, N3 and N4 while four sections were similarly marked in the South part and labelled as S1, S2, S3 and S4 respectively. The visual inspections were conducted at 28 days, 3, 6, 9, 12, 15 and 24 months after installation. The percentages of cracked portions were calculated by dividing the number of cracked sections by the total number of sections labelled on the lateral face of the roof.

3.10.2 Accelerated ageing tests

The ageing test is usually done to assess the durability of the cellulose fibre cement composites by subjecting them to cyclic drying and wetting in order to simulate natural degradation process of cement composites. Four formulations were adopted for this test by varying the bamboo fibres at 0, 0.5, 1.0, 1.5 and 2.0% but the quantity of acrylic polymer was kept constant at 10% mass of cement based on earlier obtained values. The variations were labelled as samples A, B, C and D which were mixed with sand and cement in the ratio 3:1 and water/binder ratio was 0.58. Water curing for 28 days was performed and the samples were later tested for modulus of rupture and elasticity. EN 494 standard was used to conduct the test by subjecting the samples to 50 cycles of the dry and wet procedures. The composites were soaked in 19 ± 5^{o}C water for 18 hours and thereafter positioned in an oven that is adequately ventilated at a temperature of 59 ± 5^{o}C for 6 hours. One cycle is completed when the composite has been subjected to dry and wet procedure. On completion of the procedure, another phase of modulus of elasticity rupture tests were conducted and the results were processed.

Plate 3.8: Developed composite roofplaced onwork table

Plate 3.9: Developed ferrocement roof installed in the Faculty of Technology, University of Ibadan.

3.11 Concrete Crack Repair with Acrylic Polymer Modified Ferrocement Material

In order to repair and rehabilitate concrete materials while in service, an experimental design shown in Table 3.7 was formulated and the fieldwork and laboratory tests were conducted. This experimental design was adapted from the works of Mourad and Shannag (2012); Kaish *et. al*., (2016) and Fang *et. al*. (2017).

3.11.1 Production of Reinforced Square Columns

Bamboo culms were sourced within Landmark University and allowed to dry for about eight weeks in an open field and then transported to the Farm Power and Machinery workshop for further processing. They were held in a bench vice and later divided into lengths of 900 mm before they were divided into eight strips each with a smaller radius of 50 mm. Afterwards, 4 of the strips were tied together with small steel strings to form a bamboo reinforced column. All the bamboo splits used as reinforcements consist of exposed nodes facing the upward direction to enhance adhesion with concrete because the bamboo's flexibility is based on the node position, which rigidify the end (state) sequentially, thereby hindering the collapse or buckling (Musbau *et al*., 2012). The sizes were exactly 100 mm far from one another with a mean thickness of a bamboo strip being 0.4 - 0.6 cm.

Super bond adhesive used is derived from bitumen thermoset material having characteristics such as low curing shrinkage and elevated resistant creep and provides an effective level of bonding to all materials with the exception of some minimum surface energy substances such as elastomers. The Superbond is hydrophobic and highly resistant to oil and other types of solvents. It was put on an electric stove and heated to liquefy the material from its solid.

Thereafter, 2% w/w of the binder was applied on the bamboo columns surface by dipping it into the container as well as applying brush to ensure uniform distribution of the adhesive on the entire surface area of the composite columns. Subsequently, in order to obtain a proper bonding with concrete, sharp sand was rubbed unto the binder coated surface (Plate 3.10) therefore providing a simulated steel surface with ribbed patterns. The wavy surface was anticipated to significantly enhance the bonding and strengthen the performance of the composite concrete reinforced with bamboo. The composite columns were then piled up over one another and positioned on a plain

Table 3. 7: Design for bamboo reinforced acrylic polymer modified ferrocement columns

Specimen code	**Production details**	**Process involved**	**Jacket**	**Status**	**Rep.**
P_{1-5}	Acrylic polymer mortar and bamboo as column reinforcement	Tested until ultimate failure and the load value was noted	None	Control	5
C_{1-5}	Conventional mortar with bamboo as column reinforcement without polymer	Tested until ultimate failure and the load value was noted	None	Control	5
P_{6-10}	Acrylic polymer mortar and bamboo as column reinforcement	Preloaded at 25, 50 and 75% of ultimate load	Ferrocement jacketed after preloading was ended	Repaired	5
C_{6-10}	Conventional mortar with bamboo as column reinforcement without polymer	Preloaded at 25, 50 and 75% of ultimate load	Ferrocement jacketed after preloading was ended	Repaired	5
P_{11-15}	Acrylic polymer mortar and bamboo as column reinforcement	Ferrocement jacket was placed before preloading at 25, 50 and 75% of ultimate load	Ferrocement jacketed before preloading	Not repaired	5
C_{11-15}	Conventional mortar with bamboo as column reinforcement without polymer	Ferrocement jacket was placed before preloading at 25, 50 and 75% of ultimate load	Ferrocement jacketed before preloading	Not repaired	5

Plate 3. 40: Coatingtreated bamboo reinforcementwith finesand

surface for 14 days drying in the ambient environment within the laboratory. Ten numbers of 150 X 150 X 900 mm wooden columns were made at the Carpentry Workshop within the University which was used as the formwork wherein the composite material was cast. The interior of these moulds was then lubricated with used engine oil which was sourced from the Mechanic workshop. Fine sand was passed through British Standard 1.18 mm sieve while the quantities that passed through was used and foreign objects and debris which could affect the mix were removed.

Using batching by weight, fine sand was measured and poured on the ground, cement and coarse aggregate of 20 mm sizes were also mixed in the ratio 1:2:4. Since two different sets of columns were to be produced based on the research design, the first has conventional concrete while the second group are for acrylic polymer-modified concrete. For the conventional concrete columns water was added to the mixed aggregate in the water/cement ratio of 0.68 and thoroughly mixed for a homogenous matrix to be formed.

Subsequently, little quantities of the concrete were poured into the entire ten sample moulds while the bitumen treated columns were inserted into the moulds. The constituents were shaken vigorously for sometime in order to permit the mortar to enclose them while eliminating spaces at the nodal parts and edges. The empty portion of the composite columns were afterwards packed up with concrete and permitted to cure for 24 hours in the air prior to their removal from the moulds. The processes outlined earlier were then replicated for the remaining concrete columns which were demoulded after 24 hours (Plate 3.11).

For the acrylic polymer-modified concrete columns, 10% weight of cement for the polymer was used based on the previous study conducted because it gave the best performance. 30 concrete columns were produced and air-cured naturally for 28 days before the tests were conducted. For $P_{11\text{-}15}$ and $C_{11\text{-}15}$ groups with ferrocement jacket before the tests, some adjustments were made to the square shape of the column. The reason for this is that the main drawback of square jacketed column is that it is incapable of supplying even lateral confinement in comparison to the circular form because the confined pressure is only available at the corners and therefore cracking patterns grow at the corner of the columns (Kaish, *et. al*., 2015).

Plate 3. 51: Demoulded columns

The corners were removed with the help of an hammer to a 20 mm radius from side to side for the 4 edges of the square column to obtain a rounded edge. Before applying the ferrocement jackets to P $_{11-15}$ and C $_{11-15}$ specimens, the specimens were stricken with blows from the hammer to roughen their surfaces to get a better bond between the concrete surface and the applied mortar layer. Afterwards, the roll of the wire mesh was cut using electric cutter into 340 X 870 mm, the heights were reduced by 30 mm to give a clearance of 15 mm at the upper and lower parts of the composite columns when it was wound around the columns to avoid the mesh touching the top and bottom plates of the compressive machine which could induce pressure on them and cause early failure of the ferrocement.

The wire mesh was later wound round and held together at the converging side of the column at 4 points along the length of it with copper wire and flattened with a hammer to its side. After this, portion by portion of the cement matrix was placed on the outer layers of the composite through the mesh using a hand trowel until they were completely covered with them (Plate 3.12). This same procedure was performed on the hardened column samples waiting for ferrocement jacketing prior to the test and allowed to cure under a shade in the open field for 7 days.

3.11.2 Loading to Ultimate Failure

Five samples of P $_{1-5}$ and 5 samples of C $_{1-5}$ which are the control samples were tested at the Geotechnical Laboratory, Landmark University using a 2,000 kN capacity compression testing machine. Two sets of metal stand with bolts and nuts to hold dial gauges and a flat plate which acted as the base were fabricated in the Welding Workshop in the Mechanical Engineering Department. The stands were used to keep the dial gauges in place during the test without any contact with the machine and specimen in order to give a concise reading of the gauges. The axial deflection at the upper plate of the compression machine and the lateral deflections at the mid-height level of the column samples were gotten from the two dial gauges which were clamped to the metal stand (Plate 3.13). Vertical loading from the top was applied on the column until total failure was noted and the equivalent final load was recorded.

Plate 3. 62: Applyingmortaroncolumn surface

Plate 3. 73: Column test set up

3.11.3 Preloading at 25, 50 and 75% of ultimate load

$P_{6\text{-}10}$ and $C_{6\text{-}10}$ specimens were placed under the compressive machine and loading at the rate of 25, 50 and 75% of the initial ultimate load value. This applied load subsequently led to cracks and damaged portions of the samples particularly along the length of the columns as well as chunks of concrete peeled off the sides. During each loading rate, the axial compression machine was paused and the axial and lateral deflections on the dial gauges were recorded. Then, the machine was allowed to compress the sample until the next loading rate value was attained and paused again while the deflections were recorded. Thereafter, the same procedure was followed for the last loading rate. These samples were then taken for repair.

3.11.4 Repair of cracks with conventional concrete and acrylic polymer mortars with ferrocement

The completely and partly destroyed columns were then repaired and improved using ferrocement jacketing technique stated earlier in section 3.10. Two types of mortar were applied to the ferrocement; the first one involved using conventional concrete mortar which was worked into the mesh for specimens $C_{6\text{-}10}$ while the second type involved using acrylic emulsion polymer modified mortar which was also applied into the ferrocement for specimens $P_{6\text{-}10}$. They were left to cure in the air for 7 days before testing was done.

3.11.5 Final Testing of Repaired and Non-Repaired Bamboo Reinforced FerrocementColumns

Repaired specimens $P_{6\text{-}10}$ and $C_{6\text{-}10}$ and $P_{11\text{-}15}$ and $C_{11\text{-}15}$ which had no prior loading but had ferrocement casing were tested at the loading rate of 25, 50 and 75 and the axial deflection noted at the same time with the lateral deflections. The failure patterns of the repaired and non-repaired columns were also observed.

3.11.6 Statistical analysis

Descriptive statistics, One Way ANOVA and Tukey HSD were used to analyze the results.

CHAPTERFOUR

4.0 RESULTSANDDISCUSSION

4.1 PreliminaryResults

4.1.1 PhysicalProperties of Blocks

Table4.1showsthepreliminary resultsofthephysicaltest.Asshown in the Table, thedensityof the samplesrangedfrom 2133 - 2221kg/m^3 indicatingthatthecompositeshave high densities.Thedensitiesofthecompositesdecreasewithincreasingfibrecontent.This may be duetotheenhancedpackingefficiency andproperagglomerationwithlowfibrecontentas notedby Yong(1995).Increaseinfibrecontentmay havecreatedlowerpackingefficiency andpooragglomerationwhichcouldhaveresultedin the emergenceofvoids.FromTable4.1, itcouldbeobservedthatthequantityofwatertakeninbythesamplesdependonfibre contentandthe volumeof spacespresentinthem.Whenwaterabsorptionishighthen the volumeofspacesisalsohighbecauseofitscharacteristicnatureofclustering togetherduring mixingtherebyentrappingspaces filled with water, which consequentlyturn into voids (PradeepandRakesh,2009).The water absorptionshowedanincreaseasthe fibreswere increased.Thisis becausesmallfibrecontentspossessfewervoidsbecausethey arecloselypackedtogetherandthereforewillabsorblittlewater.However,forevery further increase of 0.5% infibre content, thecomposite becomesvoidprone andlessdense. Therefore,themorethefibres,themoretheaffinityformoistureabsorptionbecausebe inghygroscopicmaterials, theypossess a strong affinityformoisture absorption.

Anotherreasonthatcouldbeadducedforthisis thatthelowerthefibre content,the lessporousthecompositematerialswouldbe.Thissametrendofincreaseforevery0.5

%fibre increment wassimilarly notedforthethicknessswellingandthereforethesame reasons forwater absorption areadduced forit.

TheANOVAtestin Table4.1showedthattheincorporationoflevelsofbamboo fibreswithcementwhenmixedtogether hadsignificant effectsonthedensities,thicknessswelling and water absorptionofthebamboofibrereinforcedcement composites.

4.1.2 Compressive Strength Test

Thecompressivestrength values ofthespecimensasshowninTable4.2werehighestat 13.6 N/mm^2whichisforthecontrol.It is obviousthatbeyondthecontrollevel,the compressivestrengthbegantodecreasesignificantly asmorefibreswereadded. This suggeststhatthe more the fibre quantity,the lower the compressive strengthandthisstrength reduction is majorlydueto thehighervolumeoftrapped airdueto availabilityofmorefibres (Ben,2007).Anotherreasonadducedforthisisthat,the bamboofibre has a lowermodulusof elasticitythanthecementmatrixhencethereductioninthecompressivestrength(Omoniyi, 2009). Itiscommonlyreportedtheworkability ofcellulosefibrereinforcedcement compositesisreducedasmorefibresareadded.Therefore,higherenergy inputisneededfor effective compactiontotake place otherwise therewillbe adecrease inthe compressive strengthbecauseofreductioninweightofthecuredconcreteduetoavailability ofvoids within its network (Okeola et al., 2018).

The compressive strengthofthe sample conformstoI.S.EN998-1(2012)which stipulatesthatmortarshavinga mixratioof 1:3of cement:sandmustconformtoM15compressivestrengthclassafter28days.Thismeantthat aminimumcompressivestrengthof12N/mm^2 isexpectedofsuchspecimens.Forthisstudy,thisclasswasattainedforbamboofibresrangin gfrom0.5to1.5%witharangeof12.4to13.6N/mm^2 beyondthislevel,the compressivestrengthreducedbelowthespecifiedstandardof12N/mm^2 at2-2.5%fibre inclusions.Hence,fibrecontentsof2.0and2.5%willnotbe consideredforfurther experiments.

Table 4. 1: Physical Properties Result forPreliminaryTest

% of fibre	Density (kg/m^3)	W.A . (%)	P-val. (0.0	Inference	T.S (%)	P-val. (0.05)	Infer.
0	2221	7.18	0.0015	Sig	2.47	0.0214	Sig.
0.5	2218	7.96	0.0010	Sig	2.54	0.0123	Sig.
1	2215	8.24	0.0019	Sig	2.76	0.0223	Sig.
1.5	2183	9.68	0.0010	Sig	2.79	0.0154	Sig.
2	2162	10.17	0.0204	Sig	2.82	0.0167	Sig.
2.5	2133	11.36	0.0221	Sig	2.96	0.0182	Sig.

Table 4. 2: Results ofCompressivestrength test

%offibre	Compressive Strength (N/mm^2)	TukeyHSD Q Stat.	TukeyHSD P-val. (0.05)	Inference
0	13.6	5.3452	0.0246	Significant
0.5	13.3	7.4833	0.0020	Significant
1	12.7	9.3541	0.0010	Significant
1.5	12.4	7.7506	0.0015	Significant
2	11.6	20.8464	0.0010	Significant
2.5	10.3	9.0869	0.0012	Significant

4.2 Results ofMainTestSamples

4.2.1 PhysicalProperties of Blocks

4.2.1.1 Density, Voids PropertiesandWaterAbsorption

Table 4.3showsthe differencesin water absorption, bulk density, density and void volume.5,10and15% additions of polymerwith nofibre inclusion(B,C,N)revealed a gradualdecreasefrom5 to15%polymercontentinthe water absorptionresult.Densityincreasedfrom5–10%polymer(BandC)at1440to1560kgm^{-3}andsimilarlyincreasedfrom10–15%polymer(CandN)at1560–1600kgm^{-3}.Thisis caused by thefillingofthevoidsby thepolymerfilmsthereby increasingtheweightofthe samples.The leastvoid or pore space wasrecordedat10% polymer content(C)at5.3%.The initialwatercuring forsevendaysassistedincementhydrationcommencement,whileair dryingenabledtheformationofpolymerfilmsinthematrixinter-phasethereby fillingthe voidsandsubsequentlyresultingintolowerporosityofthesample.Moisturemovementin theconcretewashinderedby theformedpolymerfilmswhichdevelopedaninterpenetrating structurewithinthemodifiedcementmortartherebyblocking thepores.However,atconstant polymer contentof 10%andfibre variationsof 0.5 to1.5% (D,A andR),water absorption increased asmorefibreswereadded from 1.62 to2.82%. Densityalso increasedfrom 1480to1770kgm^{-3} asthefibrecontentincreased(D,AandR)asimilarpatternwasalsoobserved forvoids as it increased from 10.7 to 16.0% as more fibreswere added.

Thisincreaseinporosityathigherlevelsoffibreadditionscouldbecausedby the higherquantity ofmoisturefrombooththepolymerpaintandwaterusedformixingaswellas the presenceofmore fibreswhich possiblyresulted intopoor compaction ofthe composites.

Waterabsorptionatconstantfibre(1.5%)andvariedpolymerrangingfrom5-10% (O,RandY) decreasedaspolymersincreased. For samplesB, CandN, reductioninwater absorptionrangedfrom2.02–1.01%forthesampleswithpolymersonly.Density alsovaried from1410–1790kgm^{-3}whileporosityrangedfrom15.3to18.7%forsamplesO,RandY.

Table 4. 3: Density, Water Absorption (WA) and Voids

CODE	**WA after immersion (%)**	**WA after immersion and boiling (%)**	**Bulk dry density (g/cm^3)**	**Bulk density after immersion (g/cm^3)**	**Bulk density after immersion and boiling (g/cm^3)**	**Density (kg/m^3)**	**Volume of permeable voids pore space porosity (%)**
CT	1.2134	5.1852	0.536	0.716	0.975	1880	8.4
A	2.3090	6.4659	0.332	0.506	0.526	1570	12.6
B	2.0179	6.6667	0.356	0.908	0.960	1440	9.0
C	1.0343	5.8436	0.101	0.310	0.336	1560	5.3
D	1.6267	5.7497	0.327	0.297	0. 326	1480	10.7
N	1.0171	5.4528	0.180	0.303	0.102	1600	5.1
O	2.9523	7.4266	0.358	0.318	0.342	1410	18.7
R	2.8205	7.0807	0.348	0.685	0.936	1770	16.0
Y	2.3841	6.0194	0.321	0.284	0.289	1790	15.3
X	1.6298	5.9176	0.341	0.602	0.927	1423	10.9
K	1.5924	5.3168	0.352	0.693	0.985	1497	10.4
G	2.3264	6.4729	0.318	0.489	0.511	1546	12.7
E	2.3008	6.4165	0.346	0.576	0.554	1581	12.1

Legend: CT – Control, B – 5% polymer, O – 5% polymer & 1.5% fibre, C – 10% polymer, D – 10% polymer & 0.5% fibre, A – 10% polymer & 1% fibre, R – 10% polymer & 1.5% fibre, N – 15%

polymer and Y – 15% polymer & 1.5% fibre, X = 0.5% fibre, 5% polymer, K = 0.5% fibre, 15% polymer, G = 1% fibre, 5% polymer, E = 1% fibre, 15% polymer.

The findings ofSumit*et.al.*,(2013)showeduniqueimprovementinphysical propertiesmostespecially thewaterabsorptionaftermodificationofthesampleswith polymerassimilarly observedinthisstudy.Itcouldalsobeinferredthat,themorethe polymers,thelesserthevoidswhichmeantthattherewouldbeimproveddurability and compressivestrength by thereductionofspaceswithinthespecimens(Abdul,2012).Itcould alsobestatedthatif the acrylicpolymerisusedforstructuresgenerallybutstoragestructures mostespecially,itwouldbe able tocontrolthe migrationof moisture intothe enclosure. Therefore,structuressuchassiloscouldbe usedtopreservegrainsforanextendedstorage timeandthequality wouldbepreserved.Inthesamevein,humancomfortisimportantwhen consideringhumanshelter,thereforefailuresanddamagescausedbymoistureingressi nto thebuilding envelopewouldbedrasticallyreducedandthebuildingswouldlastlongerwith minimal repairs occasionallydoneon them(Künzel*et. al.*, 2005).

4.2.2 ThermalPerformanceofBamboo reinforcedAEPMBRC

4.2.2.1 Thermalconductivity ofBamboo reinforcedAEPMBRC

Thermalconductivityperformancesofthetested samplesaredisplayedinFigure4.1.It couldbeseenthatspecimenwithpolymerinclusionof10%andno fibre(C)hadthe maximumthermalconductivityat109.37x10^{-5}W/mK.SpecimenNwasnextinlinewith104.9937 x 10^{-5} W/mKatpolymerinclusionof15%andnofibre. The leastthermal conductivity value was recorded for sample O at 66.77 x 10^{-5} W/mK having polymer inclusionof5%and1.5%fibres,closelyfollowedbysampleAwith76.61x10^{-5}W/mKat 1% and10% fibre with a polymer.These showedthatpolymer-modifiedmortarswithoutfibre inclusionshavepoorthermalconductivity butwiththeinclusionofbamboofibres,thevalues wereobserved to improve.

Thissituationoccurredbecausethe productsweretightlypackedcloselydue to the ongoing filmdevelopment andhydrationprocess,thusreducing theincidenceofspacesandmakingthe composite materialtopossesssmallpores(Jo*et.al.*,2014).Heatisusuallytransferredatminimal temperature around25^{o}Cby conductioninthesample under consideration.Also resultingin this output was thevolume fraction ofmoisturefromthe acrylic emulsion additive as well as thewaterused forblendingwithin thesamples.

FromspecimenB toC,therewasanabruptincreaseinthermalheatwhichwas triggered bya5%to10%riseinlatexcontentthateventually translatesintomorehumidity withinthespecimens,hencemoreconductivity.However,whenthetemperaturegrew near60^{o}C, watervapourevaporation and condensation occurred which lowered themoisture quantity inthespecimens.AminimalreductioninNconductivitywastheresultofthis condition.

Theadditionoffibresintothemixledtoa33%decreaseinthermalconductivity insampleOcomparedtoB,Rdecreasedby 28%incomparisontoCanda27%decreasein thermal conductivity in YcomparedtoN. The incorporationofbamboofibresinthecompositecementmaterialhasgeneratedano verwhelming decreaseinthermalconductivity which,if implementedinreal-lifestructuralapplications,makesitapotentialthermal insulationmaterial.Thissituationislinkedtothefibres' insulating propertiesthatcouldbe attributed to poorthermalconduction of waste wood particles.Therefore,thequality oftheconduction of heat ofthiscompositereliesonthecomponentsutilizedfor themixing. Hence,themoreinclusionswithdecreasedheatconductivity,themoretheproducthas an insulatinginclination.Inaddition,theriseinporosityledtoareductioninmaterial densityandeventually adecreasein heatconductivity(Driss*et.al*.,2013).Cristel*et.al.,*(2010), in his study showedthatlowthermalconductivity characteristicswereobservedin bagassefibreconcrete withgreaterbagassefibrecontentbecausemoreheatisdissipated as fibres wereincreased. Mounika *et.al.,*(2012)notedthatpolyester composite strengthenedbamboofibre'sheat conductivity reduceswithariseinfibrecontentwhichprovidescredencetotheoutcomeof this study.

Concretedamagedueto crackingand spalling will beminimized ifthethermal conductivityoftheconcreteislowbecauseitwillrestrictrapidtemperatureriseandtherefore damagetothesurfacelayersoftheconcrete.Duringafiresituation,thesurfaceofthe concrete willundergo an increase intemperatureleadingto a reductioninthermalconductivity becauseoftheincreaseinporosity whichisasaresultofevaporationoftheporewaterand dehydrationofthecementpaste.Thesereactionswillproduceaporous,heat-insulatinglayer atthe surface.Thislowthermalconductivitylayerwillthenreducetherateatwhich temperaturerisesinthebulkoftheconcrete(Gan,1997).Itisalsoevidentthatas thetemperatureofthesamplesincreasestheparticlesreceivethermalagitationandthereby arescatteredaway fromtheirequilibriumposition.Thethermalagitationofthesampleswas foundtoincreasegradually andapproachesstability withtime.(Appendixfortheentire thermal propertiesevaluation with time and their respectiveregression equations with graph).

4.2.2.2 Thermal ResistanceofBamboo ReinforcedAEPMBRC

R-valueisameasurementofheatflowresistance throughaspecifiedmaterial density. Thegreater theR-value, thegreaterthematerial's thermalresistanceand thus the betteritsinsulatingcharacteristics.Therefore,provided that theconductivity valuesforindividual composite materials are known, the thermal resistance will provide an easier method ofcomparingtwoinsulators together.The maximum thermal resistance was achieved at 7903m^{2}K/W for sample B comprising of polymers only, next was 7540m^{2}K/W for Nandthe last was 6961.5m^{2}K/W forCasshowninFigure 4.2 which confirms to theprevious thermalconductivityresult. Thismeansthatthe additionalincorporationof5%to10% and15%of polymeradditivesledtoadecreaseinthermalresistanceof14%and5%.From these values, it could be interpreted to mean that any additional increase in the polymer emulsion quantity could result into more thermal resistance reduction. However, for the smaller polymer additive content used, greaterstrengthforthecompositematerials could be achieved.

Thecompositescapacity heat resistanceismoreclosely linkedto quantityof fibresaddedthanthecontentofpolymersblended with the matrix.37% higher resistance in composite O more than that of sample B was observed, R had 33.4 percenthigherresistancemore than C and finallygreaterresistanceatYthanNat7.5per cent.Withreducedthermalconductivity values,higherthermalresistancevaluesareacquired. Overall efficiencyreliesoneach sample's typeofmaterial, thickness, and mass density. Ingeneral, thehighest thermal resistancewith10831.09 m^2K/Wwasacquiredin sampleO.Besides,thermalresistanceenablestoobserve the impactofusing homogenous insulators from the same constituent by increasing the layers.Therefore,thegreateststrengtheverforthisformofcomposite materialcouldbeacquiredby usingthe same materials utilizedintheproductionofsampleO to createmultiplelayers. A wallconsistsofmany distinctlayersofmaterialinactual structures.By addingthethermalresistanceofeachdistinctlayer,thecompletethermal resistance ofthe wholewall is calculated. Regrettably, R-values are unable to account for the total heat lost in building because heat movement in an enclosed building takes place in different ways. Conduction process alone can be evaluated by R-values while radiation and convection cannot be determined by it. Consequently, the ideal method to use is theU-value in this scenario because of its all encompassing consideration of all the factors responsible for heat loss in building envelopes(Vijayalakshmi*et. al.*, 2006).

Comparison of the thermal resistance to that of conductivity results showed that that of the former is higher than that of the later. This is in tandem with the findings of Luca*et.al*.,(2015) who stated that a low thermal conductivity is strongly correlated to a high thermal resistance and when the values are increased, the same pattern is still maintained by the insulating materials being tested. (SeeAppendixfor the entireThermalproperties evaluation with time and their respective regression equations with graph).

4.2.2.3 ThermaltransmittanceofBamboo ReinforcedAEPMBRC

AsseeninFigure4.3,sample B having polymeremulsionsonlyhad 12.66x10$^-$

$^{5}W/m^{2}K$,Chad11.49x10$^{-5}W/m^{2}K$andNhad13.27x10$^{-5}W/m^{2}K$,Inthatorder ofC,B andN,theminimumvaluewasobtainedrespectively.Thistranslatestothefactthat the bestdenseandcompactedparticlearrangementwithinthe composites'inner networkwas obtainedat10percentoftheacrylicpolymercontentwhichresultedintothesample

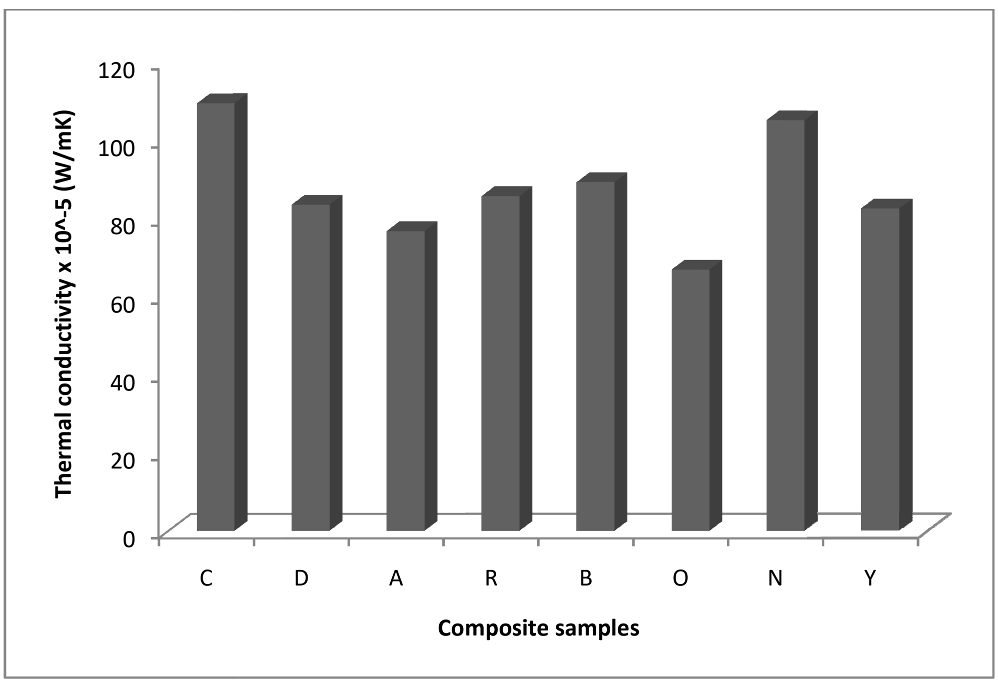


Figure 4. 1: Thermal conductivity of bamboo reinforced AEPMBRC

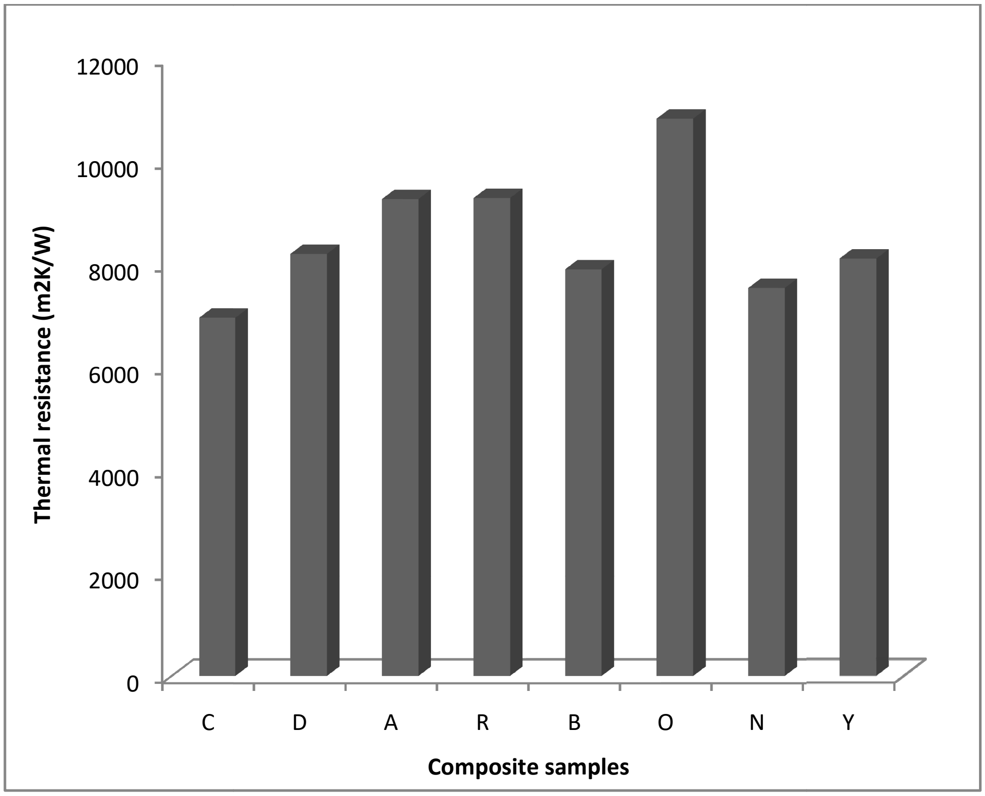


Figure 4. 2: Thermal resistance of bamboo reinforced AEPMBRC samples

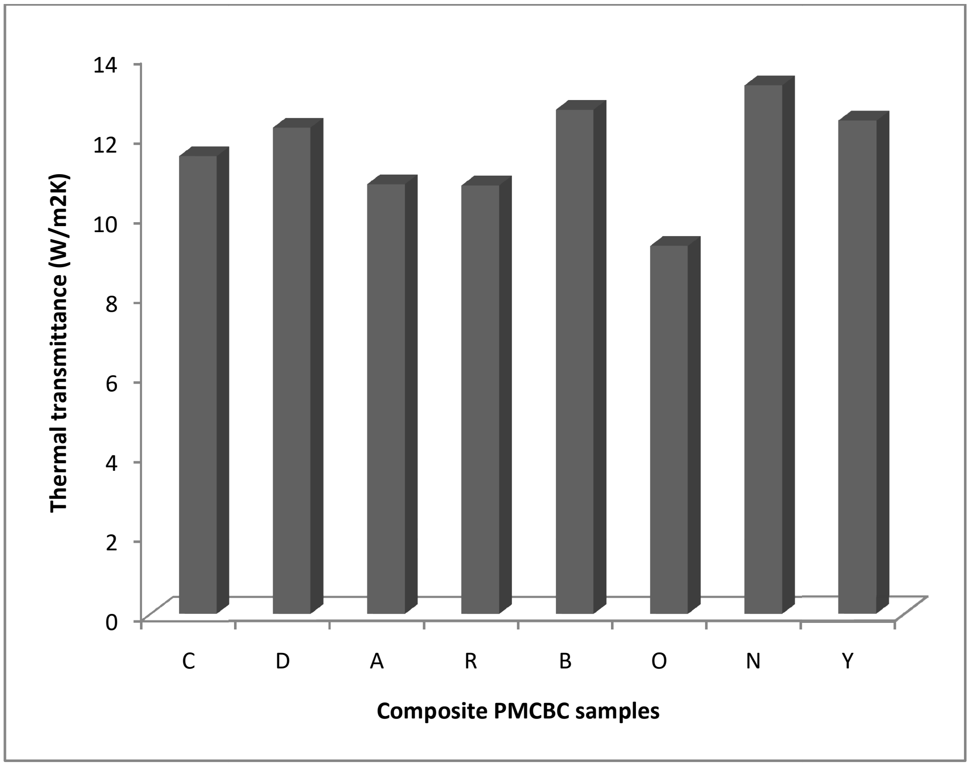


Figure 4. 3: Thermal transmittance of bamboo reinforced AEPMBRC

having theminimumtransmittance.There isalso the feasibilitythatagreaterincrease inpolymerquantityresultedin ahighertransmittanceofthecomposites,whileareduced5%polymercontentresulte din alesscompactmaterialowingtoareducedpaceoffilm developmentinside theinternalnetwork. Addition of bamboofibresintothesamplesledtoareduction intransmittancethanpolymer- only inclusivesampleswhichgavethemanadvantage.SampleBhad37%higher transmittancethanO,Cis6.7%higherthanRandNhas 6.9%highertransmittance morethanY.

The interpretation of this is that bamboo fire inclusion into the polymer modified cement mortars has resulted into improved insulating properties of the composite materials formulated.Reductions of U-values are usually attributed to enhancement of the heat insulating potentials of any material. Furthermore,ifthecomposite is for the development of building materials, a lot of energy would be conserved because of its insulating potential in utilizingitsreduced thermal transmission results (Francesco*et. al*., 2014).

Itcanbeseenfromtheanalyses above,thatmostofcompositeswithout bamboofibreinclusionhadtheworstthermaltransmittanceperformancewhilemaj orityof the compositeswithbamboofibre inclusionhadthe bestthermaltransmittance behaviour, whichmeantthat modification of cement mortars with acrylic polymer and reinforcement with bamboo fibres have resulted into the enhanced insulation of the produced composite material.

4.2.3 Micro-structuralAnalysis ResultofBamboo Reinforced AEPMBRC

The micrographfromthe SEMgottenfor thecement composites modified with acrylic polymer and bamboo reinforcement in Plates 4.1– 4.6 indicatedthat lumps of emulsion latex acrylic substances were depositedinthevoids, poresandonthe bamboo fibre surfaces.Majorfeatures observedfromtheSEMaregelsofcalciumhydroxide ($Ca(OH)_2$), unhydratedportlandcementclinkergrain and calciumsilicatehydrates(C-S-H).Thevolumesfilledby thesegels vary from60to70%forC-S-Hand7to30%for$Ca(OH)_2$oftotalvolumesofsolidsinthe totally hydratedportionofthecementpaste.Asthemainelementofsolids,theC-S-Hgels play asignificantpartinaffecting concreteproperties.Theseporesarecomparatively impermeabletowaterduetotheirsizeandverysmallinterconnectivity,inaccordanc ewith the physicalcharacteristics(water absorption)ofthe samples(Mehta,1986).Inthe $Ca(OH)_2$ solids, biggerporesizes arenotedcompared to C-S-H gels.

Movementofwatermoleculescreatevoidsandcapillary voidswithintheinternal structure. Similarly, pores arecreatedwhen openingsarenot filledwith solid cement hydrationproductswhichpavewayforincreasedporosity ofcementcomposites.Capillary voidssizein theinterfaceregionismuchbiggercomparedtothecementpaste(Tarun,1997). LargeamountsofC-S-Hgelwere developedasaproductfromhydrationandthesewere deposited at the interfaces between the fibreand thematrix with thin layers. Theorganicstructureand hydrationproductsinthe matrixinter-mingle withone anotherwhenthe fibreandthe matrix arecombined.Thesecause the materials createdinthislayer tobe strongandcompact,and this results in enhancedmechanical characteristics compared to thecontrol samples without fibreorpolymerincorporation(Plate 4.6).Thedevelopment oflatexfilms or clusters of polymerdepositedattheinterfacial zonebetweenthe modified cement mortar and bamboo fibreswas conspicuously noticed, andlikewise the cement hydrationproductssimilarly appeared within the zone.Because of the interaction between polymeric materials and hydratedproducts, the presence of thesesubstancescontributestothecreationofa complex internal network arrangement;thisisevidentinPlates4.2,4.4,4.5 and4.6.Thisinterconnectivity betweenthesecomponentsisfollowed byanenhancementof the modified cementitious materialsmechanical characteristics betterthan the reference specimen.

Bambooreinforcedacrylic polymer modifiedcementcomposite microstructural features displayedin Plate4.5 showedthat alsoappearingin thepores werepolymerlumpsof acrylicemulsionandaflatbamboofibre.Itcouldbe observedthatthe bamboofibresandthe productsofcementhydrationwereproperly blendedanddepositedbetweenthe bambooandthematrixattheinterfacelayer.Therealsoappearsatiny voidandmicro-crack. Asthenumber ofacrylicpolymeremulsionsaddedtotheconstituentsincreased,therewasa relativereductioninthe occurrenceofvoidsbetweenthecompositematerials.Theseresulted inmoredepositionofsolidmattersattheinterfacelayer,thereby leadingtoenhanced mechanicalproperties.Thiswasalsothecase forthe controlsamples.The obtained mechanicalresultssuchasflexuralandsplittensile strengthare inexcellentagreementwith these findings.

AsobservedinPlate4.1,aninterpenetratingnetworkstructure between the cementparticlesand the continuous film from thepolymer isnotedforcementmortar modified with 0.5% polymer,however, the utilizationof agreateramountof latex polymerfor fibreand cementmodificationproducesadense polymerfilm on cementgrain as shown in Plate4.6.Theuseof15% as the maximum acrylicemulsion polymercontent, therefore,bindsthecementgraintightly togetherandhelpsin hydrationof thecement grain. However,theincreasedpolymeremulsion content withinthe cementcompositeswouldlikelyresistwater percolationthroughdense polymerfilm development(thiswasseenfromthe water absorptionresults). Subsequently,resistance tomore cement hydrationprocess will occur(Byung*et al.*, 2014). This issimilartothesituation observedatthe60thdayresultsforsomeofthemechanicaltestsconductedinwhichdro psinstrength wereobserved.

Plates 4.1 – 4.6 show thatasthepolymercontentsincreased, thecalcium hydroxidegelsreducedwhichprovetheroleofpolymerfilmsincreating adense microstructurewithinthematrix.TheporesizesshownintheSEMbecamesmallera smorepolymercontentswereadded. Thisisbecausethevoids arefilledwithpolymeremulsionasmoreareadded.Thesepolymersgreatly decreasethe likelihoodofmoisturepenetrationthroughtheacrylicemulsionpolymersandhighl y enhanceits long-term durability potentials.AsimilarSEManalysisby Shaker*etal*(1997)showed similarobservationusing styrene-butadienelatexmodifiedconcretemortars.Further explanationbyYe*etal*(2013)showedthatascementhydrationprogresses,thecapill ary waterisusedup,thereforeacontinuously closed-packedlayerisformedonthecomposite surfacebythe flocculation actions ofthepolymer

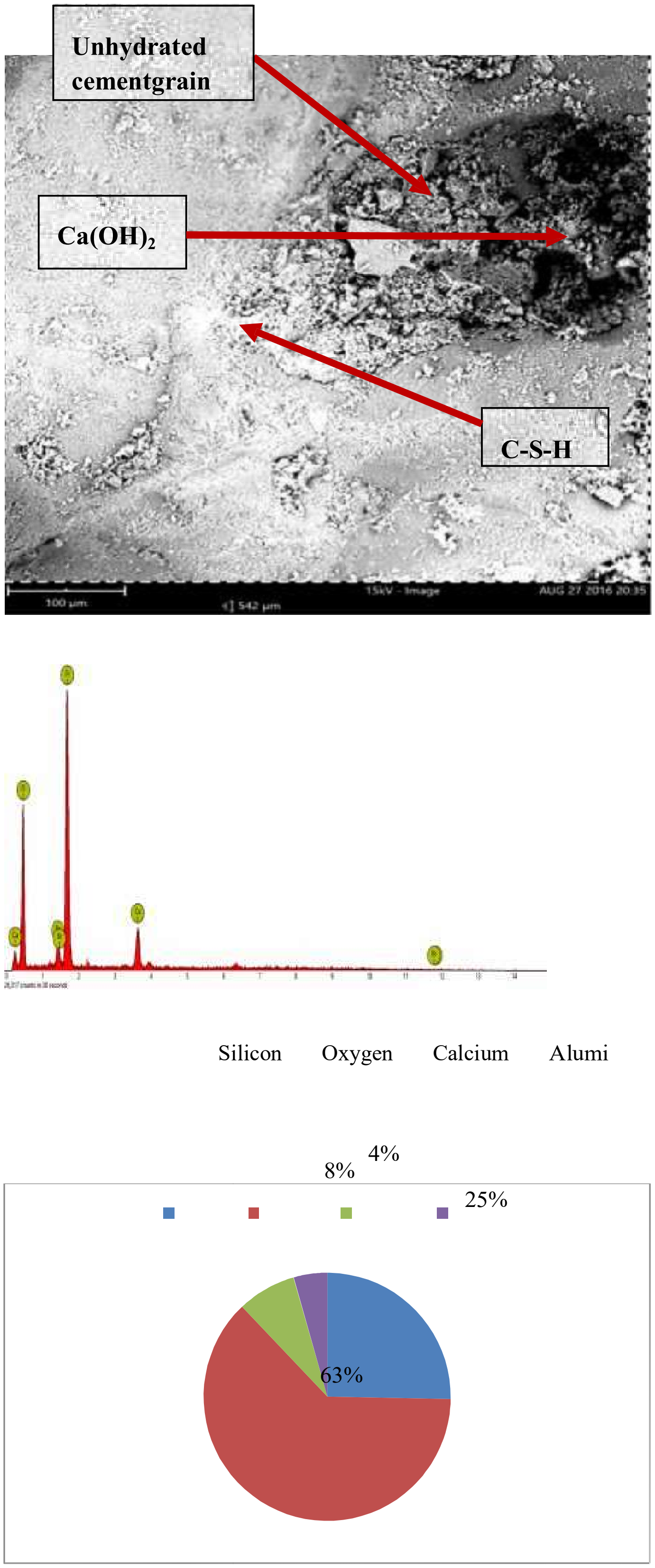


Plate 4. 1:SEM, EDSand distribution analysisofsample B

particles.

Lastly,acontinuousfilmcoalescesby thecloggedpolymerparticlesonthecement hydratessurface, andthefilminterpenetratesintoa monolithic networkthroughoutthe cementhydrates.Itcouldalsobe observedthatsiliconelementalsofeaturedinsome of the microstructure of the samplesbecause the bamboofibrespossessrichdepositsof organic silicateinitsfibresandthemajoronesaretheligninandhemicellulosesasstudiedbyKalia *et.al.,*(2011).However,alargerpercentage ofthishadbeenreducedthroughalkalitreatment duringthesamples preparation.

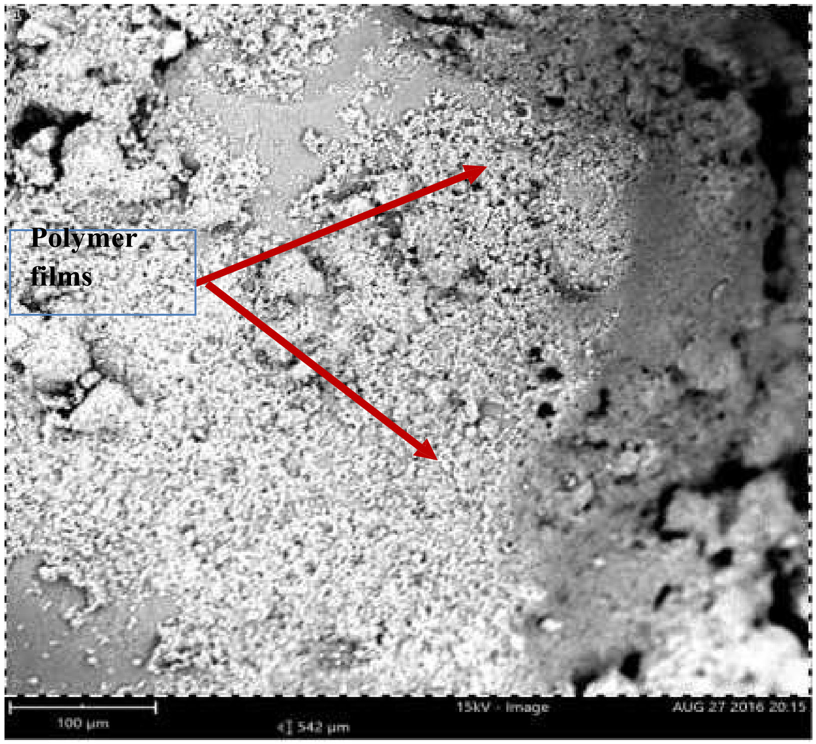
4.2.4 Mechanical Properties ofAEPMBRC

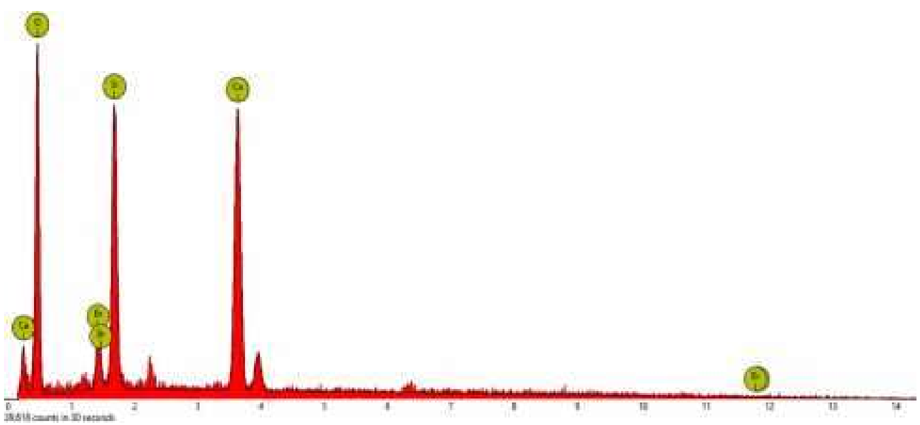
4.2.4.1 CompressiveStrengthafter28 Days

Theresultsforcompressivestrengthafter28days areshown inFigure 4.4. Allcontrolmixes (CT) hadlow performance when comparedwiththe remaining sampleswith and without polymerandfibreinclusion. Compressivestrength valuesof26.55N/mm^{2}for5%polymercontent,28.0N/mm^{2}for10%polymercontentand29.1 N/mm^{2}for15%polymercontent as shown inFigure4.4.

Thisshowedanenhancement of the strengthastheacrylic polymerquantitywasincreased;the same patternwasreported by PriyadharshiniandRamakrishna,(2014)whostatedthat an improvement in the compressivestrength after 28 days was noticed invegetablefibrereinforcedpolymermodifiedcementcomposite on comparison with the reference.

On theotherhand, the addition ofvaried polymerat constant fibreweight into themix such as, 5% acrylic polymer inclusion and 1.5% fibre composition (sample O) gave 28 N/mm^2 while1.5%bamboo fibrecontent with10%polymerat(sampleR)and15%acrylicpolymer inclusion and 1.5% fibre (sample Y) had closely matched strength at 29.6N/mm^2 and 29.5N/mm^2 respectively.Thisimpliesthatthehighestcompressive strengthwasat10% polymerat1.5%fibrecontent(sampleR)with29.6N/mm^2.Thismeans that15%polymer contentaddedlittle improvementtothe strength. Sampleswithvariedfibresatconstant polymer(D,AandR)showed a progressiveincreaseinstrengthasthefibreswereincreased.





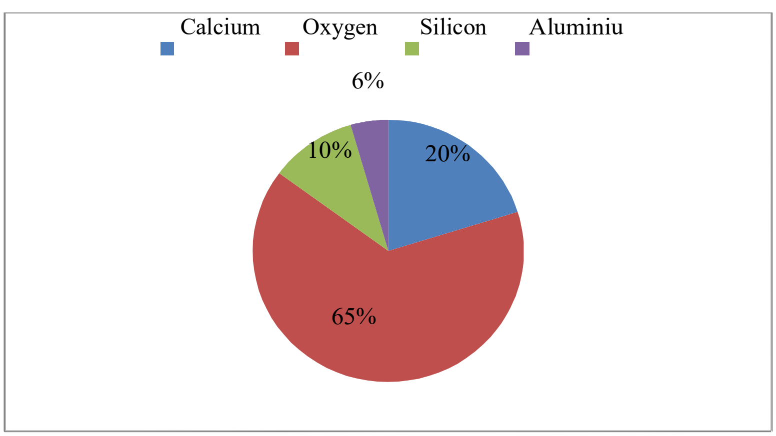


Plate 4. 2:SEM, EDSand distribution analysisofsample O

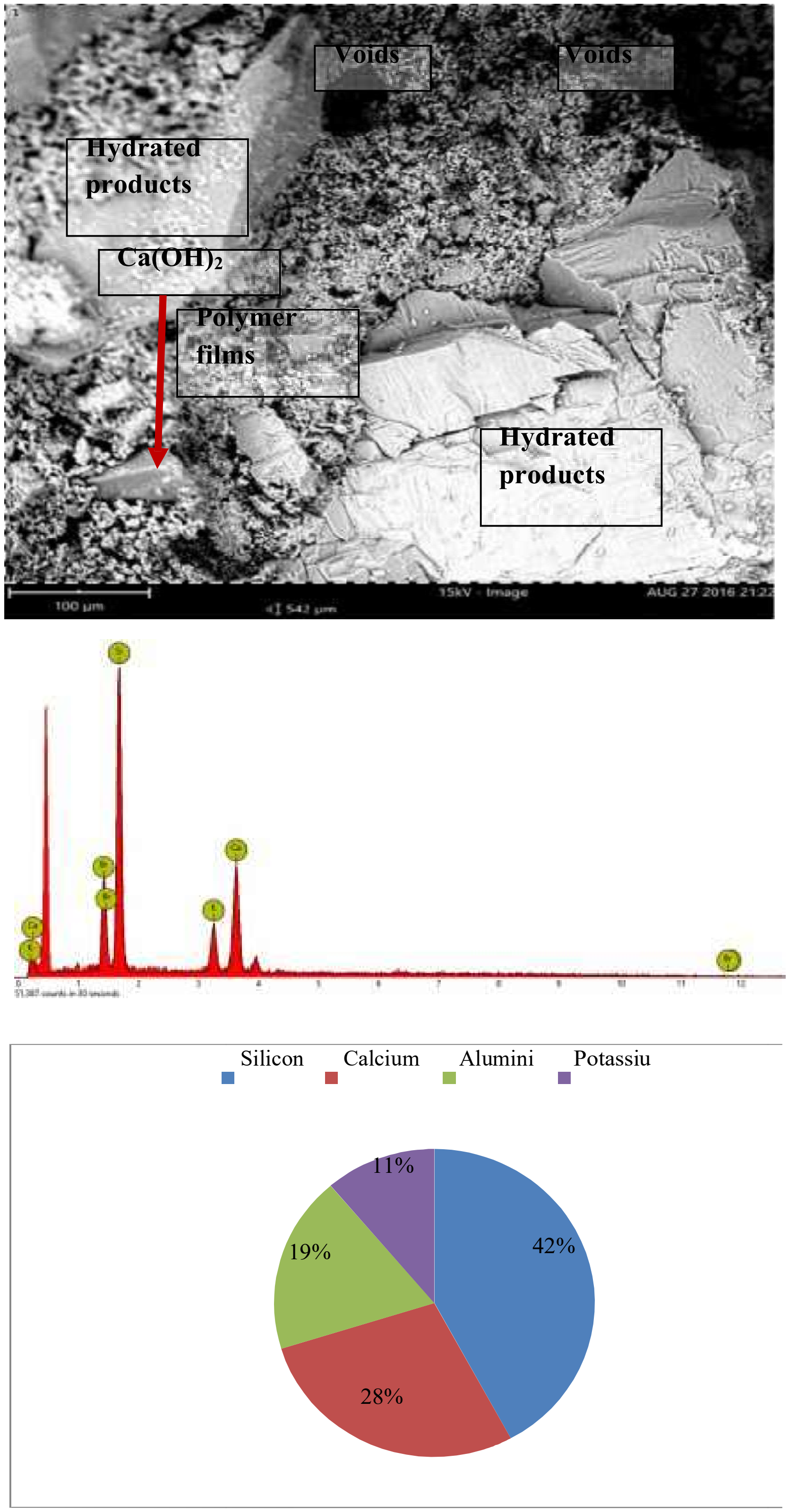


Plate 4. 3:SEM, EDSand distribution analysisofsampleC

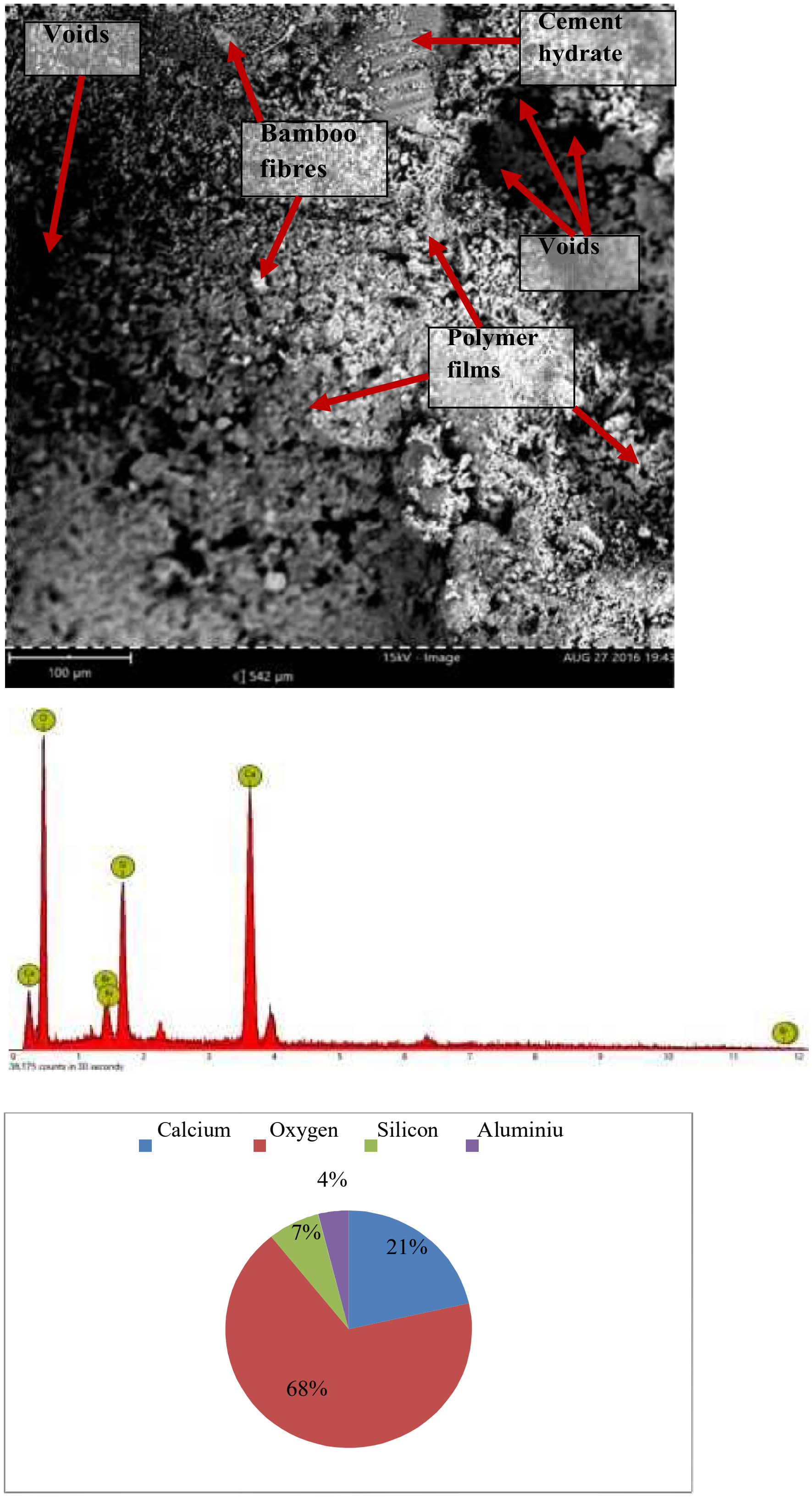
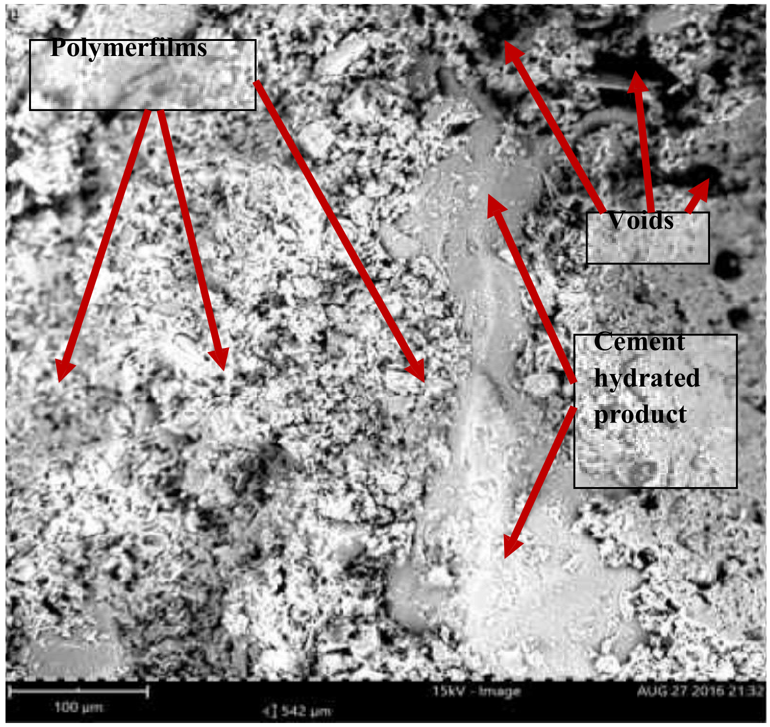
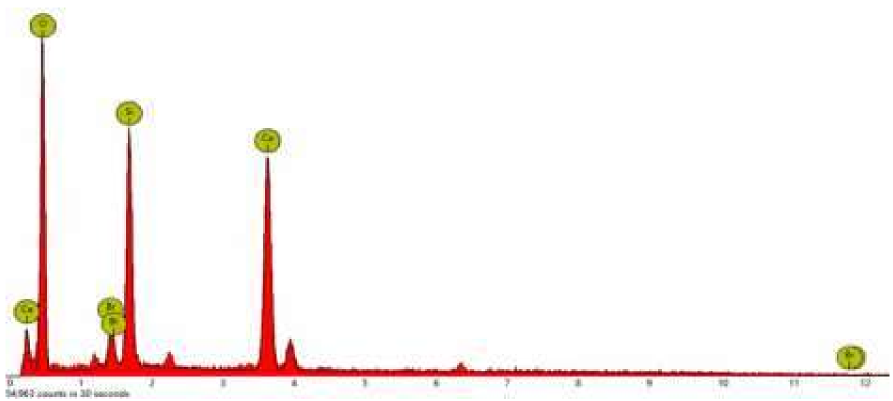


Plate 4. 4:SEM, EDSand distribution analysisofsample R





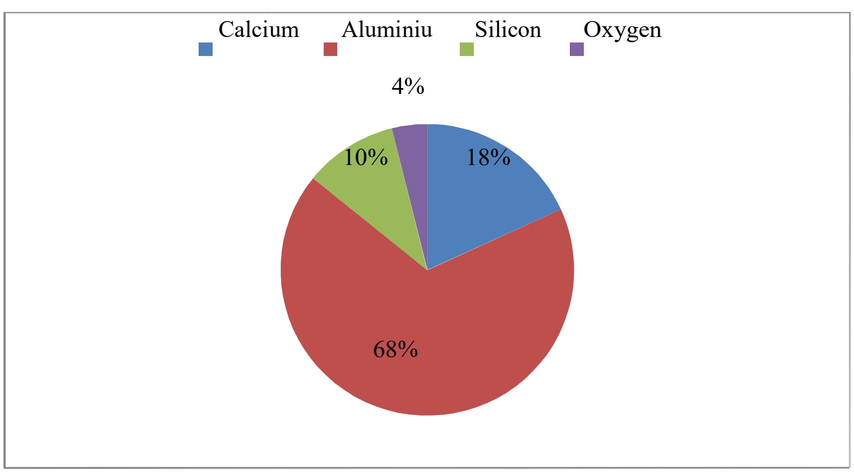


Plate 4. 5:SEM, EDSand distribution analysisofsample N

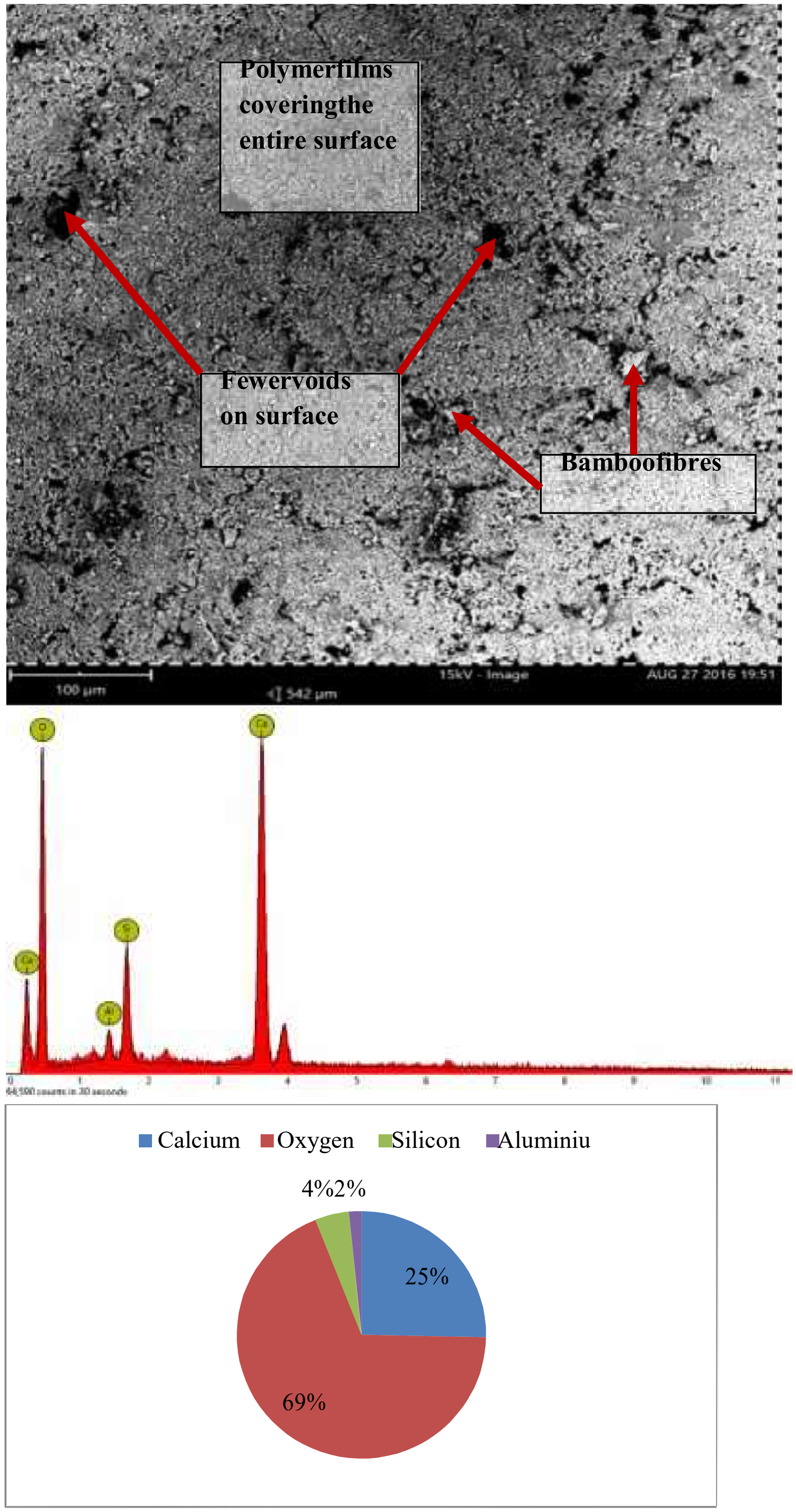


Plate 4. 6:SEM, EDSand distribution analysisofsample Y

This had also been confirmed byStancato*et. al*., (2005) who reported that using a higherquantity ofpolymer ina polymer modified concrete reinforced with cellulose fibreswillgreatly leadtoanenhancementofthecompressive strengthandsimilarly ithasbeenstatedthatatadefinitefibrelevelcontentinreinforced concrete,the compressive strengthwillimprove because thefibresbridgedthe gapformedby cracks.Therefore,itissecure tostate thatthe composite materialdevelopedhasenhanced characteristicswhichcouldnothavematerialisedifthey hadexistedseparatelywithoutbeing used as composites.

4.2.4.2 CompressiveStrengthafter45 Days

After 45dayscuring, the compressive testshowedthatCandN sampleshadthe same valueat39.41N/mm^{2}whileBhad35.88N/mm^2 thisshowedthatuntilahighercontentof virginpaintsisaddedthere isnoeffectonitsstrength(Figure 4.4).Also,the effectof more curingtimeonthecompositematerialisvisible whichtranslatestomoreimprovementonthe strengthofthematerial,thisisinconjunctionwiththehydrationofthecementandthe coalescenceof the polymer filmswhichtookplaceatthesame time.Sample Owith1.5% bamboo fibreand 10% acrylicemulsionhad theleast strength at 38.88N/mm^2 among sampleswithconstantfibresandvariedpolymers,samplesRandY were tiedatthe same valueof39.19N/mm^2. Compositionswithconstantpolymersatvariedfibresshowedthat sampleDhad34.76N/mm^2,Aat38.24N/mm^{2}andRat39.19N/mm^{2}respectivelyasseenin Figure4.4.This meant that after 45 days, a more significant enhancement in the compressive strength took place because the pores for moisture penetration have been reduced significantly because of the extended curing beyond 28 days. Thepolymeradditivealso resulted into enhancement of the cement mortar strength due to its ability to retard rapid cement hydration rate. This mechanism enabled the development of films and water molecule evaporation at the same pace leading to homogenous strength development within the composite.

The One way ANOVA analysis (see details in Appendix P) showed thattherewasasignificantdifferencebetweenthe28thand45days' strengthat p-value of 0.00002671whichmeantthatthe bamboofibresandpolymer have significanteffect on thestrengthas the curingdays progressed.

4.2.4.3 CompressiveStrengthafter60 Days

ItcouldbeseenfromFigure4.4thatsampleBhadanincreaseof14.6%overthe previousvalueat45days,Chad14.2%higherstrengththan45daysresultandNhadthe sameincrement in strength. Samples with constant fibre reinforcement andvaried polymer constituentsshowedthatsamplesRandYhadthebestperformanceintheirgroupat44.34 and 44.37 N/mm^2.

Compositions with constant polymer and varied fibresindicated an increasein strengthasthefibreswereincreased.Dhad39.57N/mm^2,Ahad42.66N/mm^2 andRhad 44.35N/mm^2.Itisclearfromthisresult thatat60daysthemaximumstrengthforthe compositematerials is gotten from the compositions of10% and 15%polymerwith 1.5%fibre addition to thematrix.

ArelatedstudybySumit*et.al.,*(2013)wherethepolymeremulsionwerealsovaried by 5%,10%,15%and20%ofcementwereusedtoproduce polymermodifiedmortarthat wasreinforcedwithjutefibres,theresultofthecompressivestrengthtestoverthecuring daysadoptedalsoshowedthatpolymer contentdosage upto15% leadtoa improvementin compressive strengthofcellulose fibrereinforcedpolymermodifiedmortarshowever,this strengthcould be comparableto orbetterthan thecontrol samples. The One way ANOVA (See Appendix P for details) showedthattherewasasignificantdifferencebetweenthe45thand60thdays compressivestrengthatp-valueof0.0208whichmeantthatbamboofibresandpolymerhave significanteffect on thecompressivestrength as the curingdaysended.

4.2.4.4 Flexural Strengthafter28 Days

After28daysofcuring,CandN(10and15%polymersonly)jointly hadthehighest flexuralstrengthamongcompositionswithpolymersonly (Figure4.5). SampleBwith5% polymercontenthad6.8N/mm^2 whileCandNhad7.6N/mm^2.Thisfollowedthesame patternobservedduring thecompressivestrengthtestthatasthepolymersareincreasedtoa certainlevel,therewillbenochangesinthecorresponding strengthofthematerials.For sampleswithvariedpolymer contentatconstantbamboofibres,sample O(1.5and5% fibres andpolymer)at9.3N/mm^2 hadtheleastflexuralstrength;whilethehigheststrengthwas gottenatsamplesRandY(constant1.5%fibreand10and15%polymer contents)with closelymatchedvaluesat9.83N/mm^2 and9.85N/mm^2 respectively.Compositionswith varied bamboo

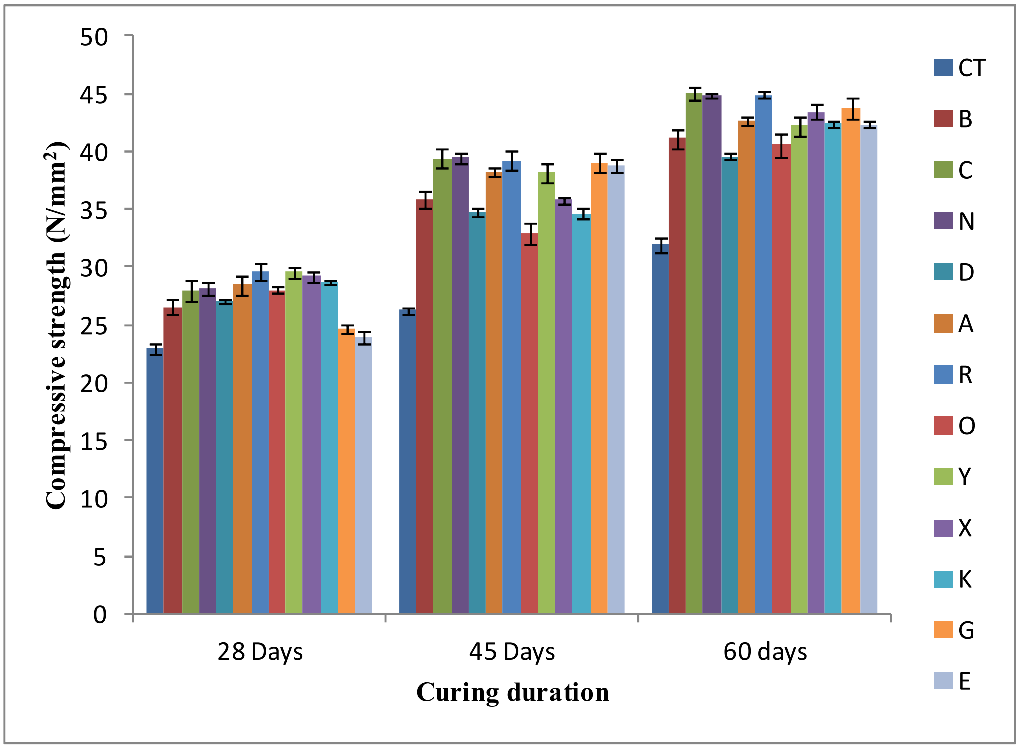


Figure 4. 4: Compressive strength across curing days

Legend: CT- control, B- 5% polymer, O - 5% polymer & 1.5% fibre, D – 10% polymer & 0.5% fibre, A – 10% polymer & 1% fibre, R – 10% polymer & 1.5% fibre, N – 15% polymer, Y – 15% polymer & 1.5% fibre, X – 0.5% fibre & 5% polymer, K – 0.5% fibre & 15% polymer, G – 1% fibre & 5% polymer and E – 1% fibre and 15% polymer.

fibresatconstantpolymer contentshowed an increasein flexuralstrength as the fibreswere increased.Thisresultshowedthatwithfibre additionthere isresistance tocrack formationandimprovementinstrengthvalue whencomparedwithsampleswithacrylic polymersalone.Themaximumstrengthafter28dayscuringwasgottenat9.83N/mm^{2}and9.85 N/mm^2 whichareforsampleswith1.5%bamboofibreand10%and15%acrylic polymerinclusions.Theacrylicpolymerinclusionintothematrixhadconsiderablepositive effectontheflexuralstrength withanincreaseof87%overthecontrolsampleswhen comparedwiththe highestvaluesatCandN(10and15% polymersonly),alsothe combined effectsofadditionoffibreswiththepolymer(RandY)ledtoanimprovementandincrease of145%in strength overthe control samples.

A similar reportbyIsmail*et.al.,*(2008)whenbagasse fibre polymer cementcomposites werestudiedstatedthatanimprovementinbending strength wasnoticedon the increaseofthe polymerdose untilthemaximumresultwasattained.Themajorreasonsgivenforthisisthat thereisthedistributionofthepolymeremulsionintothespacesandvoidsofthebagasse fibre.Anotherexplanationforthissituationisthatwhen the lossofwaterbyevaporationleadsto dryingof polymers, thesuspended polymerparticles arepacked together. The capillaryforces produceforcesofadequate magnitude duetotheconcave menisciatthewater-airinterfaceto overcometherepulsiveforcesbetweenpolymerparticles,whicharethenintouch,whileat thesamemomentcausing ariseinwater-phasesolublematerialconcentration.Significant capillary pressureisexerted by theevaporationoftheremainingwater,whichwillleadto greater contact in thelatexfrom thesuspended polymermolecules.

Thus,surfacetensionandcapillary forcesarethedrivingforcesfortheagglomeration of polymer molecules.These forcesrisewith reducedparticle size due toeither waterlossor autohesionandcoupledwiththe amountof polymerused,thegrowthof the finalmechanical characteristicswill beaffected (Ismail*et. al.*, 2008).

4.2.4.5 Flexural Strengthafter45 Days

Figure4.5showedthatsampleCandN(10and 15%polymeronly)hadmaximum strengthoverthesamples with polymers onlyat8.43 and 8.49N/mm^{2}and B (5%polymer only) also had 7.10 N/mm^2.

Thisresultshowedthatthe more thepolymersadded,the morethe strength. CompositionswithconstantfibresatvariedpolymersindicatedthatOhadtheleastvalueat10.0

6 N/mm^2 while R and Y had similar values at 10.95 N/mm^2 and 10.97 N/mm^{2}respectively.Samples with constant polymercontent andvariedfibres showed thatDand A hadthe leastresultsat7.83N/mm^{2}and9.12N/mm^{2}withthe higheststrengthobtainedatR with 10.95 N/mm^2.

The enhanced flexural strength was the result of the impacted ductility into the cement composite by the bamboo fibres in comparison with polymer only samples. Thefibres embeddedwithinfibrereinforcedconcreteactasacontrolagainstcrackingby changingthe behaviour ofthecompositeonceithascrackedthroughinterlocking ofthecracksanditalso offerspost-crackingductility(AiswaryaandElson,2014**)**.However,samplesRandYhad the highestflexuralstrengthbecause thematrixporeshadmorepolymerfilmsandpossibly because little or novoidsexistedwhichcouldoccur whenusingnaturalfibresas reinforcement.

One way ANOVA (see Appendix P for details) showedthattherewasnosignificantdifferencebetweenthe28th and45th daysflexuralstrengthatp-value of0.2233whichmeantthatbamboofibresandpolymerhad no effect on the flexuralstrengthas the curingdaysprogressed.

4.2.4.6 Flexural Strengthafter60 Days

Minimalincreaseinflexuralstrengthwasobservedas10% to15% more acrylic polymerswereaddedtothemixasseeninFigure4.5.Thepeakstrengthforcompositions withpolymersonlywasrecordedatNwith11.18N/mm^2 whileChad11.10N/mm^2 andB had10.56N/mm^2,thisresultissimilar tothatobtainedfor the 60dayscompressive strength. Thisamounttoincreaseinstrengthof 31.68%for sample N and31.67%for sample Cwhen compared with thestrength obtained after45days curing. For compositesamples with constantfibreinclusionandvariedpolymers,sampleOhadtheleastflexuralstrengthat 11.63N/mm^2,whileR had11.74N/mm^2,Yhad 11.74N/mm^2. Compositionswithconstant polymer andvariedfibrecontentshowedanimprovement inthe bendingstrengthasthe bamboo fibreswere increased. Themaximum result from this group is11.74N/mm^{2}forsampleR.

Thistrendisalsosimilartothe situationobserved afterthe 45dayscompressive strengthresultanditshowedthatthereisimprovementinstrengthafterthe peakhasbeen reachedthereforefurtheradditionofpolymerstothemixhadminimaleffectontheresult.

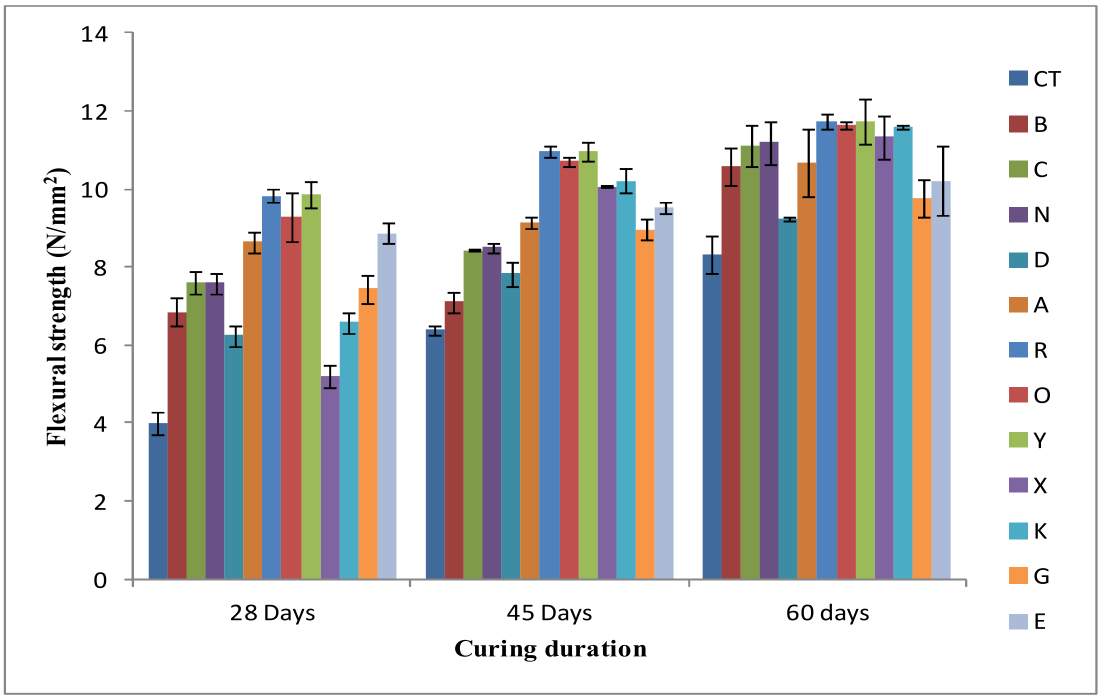


Figure 4. 5: Flexural strength across curing duration

Legend: CT- control, B- 5% polymer, O - 5% polymer & 1.5% fibre, D – 10% polymer & 0.5% fibre, A – 10% polymer & 1% fibre, R – 10% polymer & 1.5% fibre, N – 15% polymer, Y – 15% polymer & 1.5% fibre, X – 0.5% fibre & 5% polymer, K – 0.5% fibre & 15% polymer, G – 1% fibre & 5% polymer and E – 1% fibre and 15% polymer.

One way ANOVA (see Appendix for details)showedthattherewasasignificantdifferencebetweenthe45thand 60thdays flexuralstrengthatp-value of0.0130.Thismeantthatbamboofibresandpolymerhad significanteffect on theflexural strength as thecuringdaysended.

4.2.4.7 SplitStrengthafter 28 Days

SamplesCandNwithacrylicpolymercontentsof10%and15%had4.2N/mm^2 whichisthehighestperformanceamong thesampleswithpolymersonly.Thiswasfollowed bysampleBat4.1N/mm^2 (Figure4.6).Thisfollowedthesamepatternobservedatthe28 daysflexuralstrengthresultandthereasonstatedforthisphenomenonalsosufficeforthis testalso.Itcouldbe deducedfromthisvalue,thananincrease inpolymercontentwouldlead toanimprovementinthestrengthproperty oftheconcrete.SampleRwith10%acrylic polymercontentand1.5%bamboofibreadditiongavethebestperformanceamong the samples with constant fibre reinforcement and varied polymer contents at 4.96 N/mm^2, sampleYhad 4.92 N/mm^2, and this showed that aslight margin of difference existed betweenthemasseeninFigure 4.6.The inclusionofvariedbamboofibresatconstant polymercontentshowedincrease insplitresistance asthe fibreswere increased.The maximumvaluewasnotedat sampleRwhich isindicativeofthefactthat themorethefibres addedatthe samepolymer content,the moretheimprovementinthe concrete strength.This performancecouldbecreditedtothefactthatthepresenceofpolymersonly inacomposite possesses moreresilienceto resist forces in tension becauseit has strongtensileproperties becauseofpolymerstructuresthatweredevelopedduringtheblendingandpermeationofth e polymerand products ofcement hydrationtogether (Baoshan *et. al.*, 2010).

4.2.4.8 SplitStrengthafter45 Days

FromFigure4.6,itcouldbeobservedthatamong compositeswithacrylicpolymers only,sampleCandNhadthehigheststrengthat4.61N/mm^2,whileB had4.57N/mm^2,this followedthesamepatternasobservedbeforeandthereasonsarethesameasstatedearlier. D,AandRsampleshad5.69N/mm^2,6.37N/mm^{2}and6.89N/mm^2.

There wasanoticeable improvementinstrengthonadditionoffibrestothe compositebecausethe lateral surface area of bamboo fibres in contact with the polymer constituents and cement products increased. This increase was initiated bythehigh aspectratioofthefibre,thereforebonding betweenthecement,polymerandthefibreswere improved.Thefibrepossesseshightensilestrengthleading tothechangeinthesystemof rupture from fibre breakage to fibre pulling out from the hardened constituents. This invariably typifiesthatthestrongbondingamongcement,polymersandthefibresdirectthe mechanism in operationbetween thefibres and thematrix (Khoramiand Sobhani, 2013).

One way ANOVA (See Appendix P for details)showedthattherewasasignificantdifferencebetweenthe28thand45thdays split strengthatp-value of0.0327. This meantthatbamboofibresandpolymerhad significanteffect on the flexural strength as thecuringdays progressed.

Figure4.6showedthatthereisanincreasedresistancetosplitting forcesasmore polymerswereaddedintomixwhenconsidering thesamplespolymersonly.At5%acrylic polymer,thestrengthwas5.61N/mm^2,whileat10%polymerinclusionthestrengthgave 5.86 N/mm^2 which translates to 4.45% improvement in resistance to splitting of the composite,afurtherincreaseofpolymerto15%contentofthecementmassgaveastrength of5.89N/mm^{2}which is similarlyan upward increment of0.5%in strengthofthematerial.

4.2.4.9 SplitStrengthafter60 Days

Thisgoestoshowthatsplittensilestrengthproducedanimprovedproperty asmore polymerswereaddedtotheconcretewhenconsidering sampleswithnofibres.Afurtherlook atFigure4.6alsoshowedthatOhadtheleastresistancetosplittingat6.96N/mm^{2}whileA had7.35.4N/mm^2,RandYproducedsameresultat7.67N/mm^2 respectively.Theleast performancewasrecorded forDat 6.62N/mm^{2}inits group.Theeffect of fibre reinforcement across thesegroups ofsamples with fibres and polymersaremorepronounced; this effect was noticedmore atRandYbecause the fibresoffereda more cohesiveand combinedresistance tosplittingforcesatanincrementinstrengthof35.4%morethanwhenonlypolymersexist in thesample.

One way ANOVA (See Appendix P for details)showsthattherewasnosignificantdifferencebetweenthe45th

and60[th] dayssplitstrengthatp-value of

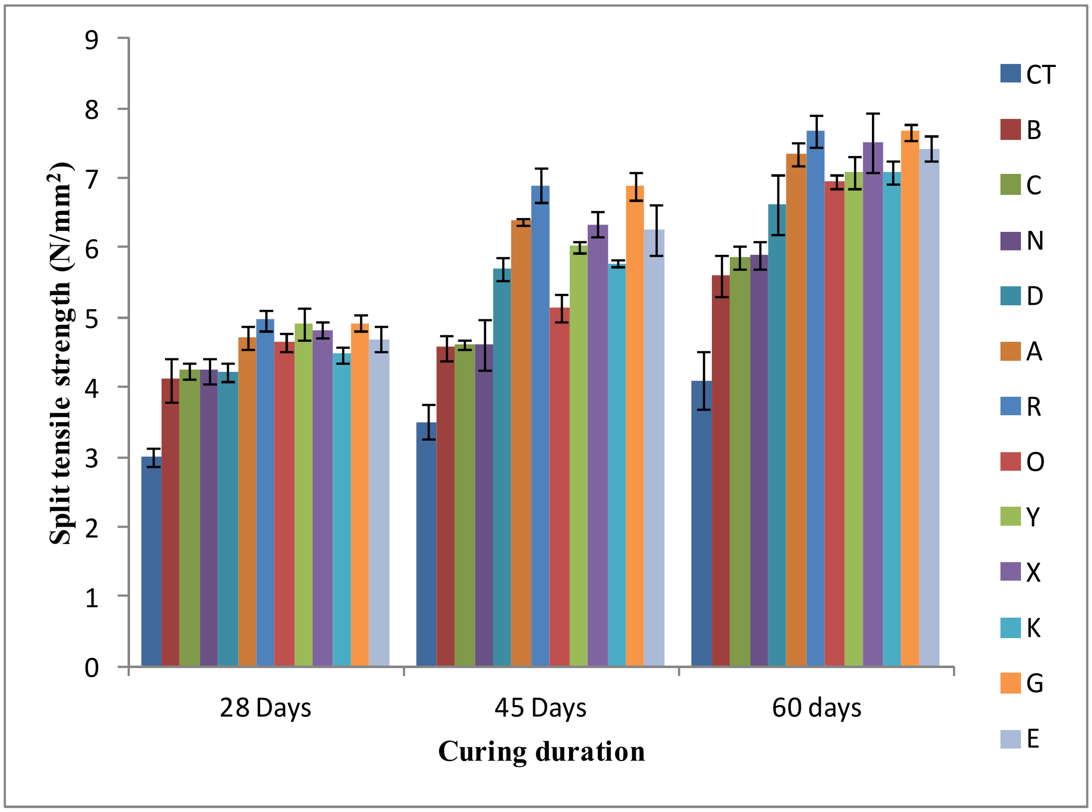


Figure 4. 6: Split tensile across curing duration

Legend: CT- control, B- 5% polymer, O - 5% polymer & 1.5% fibre, D – 10% polymer & 0.5% fibre, A – 10% polymer & 1% fibre, R – 10% polymer & 1.5% fibre, N – 15% polymer, Y – 15% polymer & 1.5% fibre, X – 0.5% fibre & 5% polymer, K – 0.5% fibre & 15% polymer, G – 1% fibre & 5% polymer and E – 1% fibre and 15% polymer.

0.0771.Thismeantthatbamboofibresandpolymer hadno significanteffect on theflexural strength as thecuringdaysended.

4.2.4.10 Comparison betweenMechanical Properties

i. Comparism between compressive strength and curing duration

Figure4.4showedtheresultsforeffect ofvariedbamboofibresandpolymersonthe 28,45and60dayscompressive strength. Mixeswithpolymersaloneshowedanincreasein compressivestrengthaspolymersincreaseaswellasthecuring days.After28dayscuring, sampleB had26.54N/mm^{2}whileat45daysitwas35.89N/mm^{2}resultingintoanincreaseof 35%,als oafter60dayscuring,therecordobservedvaluewas41.14N/mm^{2}whichalsogave anincre aseof15%forthisparticularsample.Alsoconsideringanothersample C,thevalues obtained were 28 N/mm^2, 39.41 N/mm^2 and 44.99 N/mm^2 for 28, 45 and 60 days respectively.Asignificant increaseinstrengthwasnotedforthesamplefrom28to60 days. Theearly strengthdevelopmentofthecompositeswasenhancedwhichwascaused by theadditionoflatexpaintintheconstituentsandthisledtocovalentbondsbeing developed betweencalciumionsinthecementhydratesandtheultrafineparticlesinthelatexpaints re sulting toimprovementofthecementhydrationprocess(Ye*et.al*.,2013, Nasserand Jason, 2014).

Therewasanincreaseinstrengthastheduration of water curing increased. Thiscouldbe because of presence of microfillers' particle size arrangementfromtheacrylic polymerandthequantityofthegranularmoleculesinthecompositematerial.Oneother majorbenefit ofincreased dosageof polymers in materials is that an increment in the mechanicalstrengthwouldbeguaranteedtoa particular leveland after thishasbeen reached thegrowth rateofthestrength will bestatic(Gorninski*et. al*.,2004).

Addition of fibre into the cement composites produced an increment in the compressivestrengthwhich ranged from 27.02 N/mm^2 – 39.57N/mm^2 forsampleD, 28.48N/mm^2 –42.66forsampleA,and29.57N/mm^2 –44.35N/mm^2 forsampleRafter28,45 and 60 days test hadbeen done.Compositions with constant fibres and variedpolymer contentssimilarlyshowedthesamepatternofincreasefrom28to60days. SampleOranged from28.02N/mm^{2}to 43.52N/mm^2, sampleR isfrom29.57N/mm^{2}to44.35N/mm^{2}and lastly sampleY is 29.54N/mm^{2}to 44.38 N/mm^2.

Ingeneral, the higheststrength was attainedafter60days testatsampleY which is closely matched by sampleRwithadifferenceof0.07%whichcouldbesaidtobemarginal. Thisobservationwasalsosimilarly reported byStancato*et. al*., (2005)whoobservedthattheuseof higher polymer content in a polymer modified vegetablefibrecement composites considerably boostedthecompressivestrengthofthematerial.Alsoithasbeencommonly notedthataquantifiedleveloffibreincorporationinto reinforcedconcretewillyieldan enhancedcompressivestrengthby interfacingbetweensuccessivecracksinareinforced concrete.Thecementcompositeproducedconsequently hasenhancedcharacteristicswhich emergedafterblendingthem together.

One way ANOVA (See Appendix P for details) showed that therewereno significant effects ofvarying the polymersandatconstantfibres,nor varying thefibresandkeepingthepolymersconstantas welltheuseofvariedpolymersonly ontheflexuralstrengthofthecontrolsamples.Thep- values obtained were0.3357, 0.2855 and 0.2609 respectively.

ii. Comparison between flexural strength and curing duration

Theduration ofcuring hadamorepositiveimpactonthegreaternumberofthe specimenswithfibresthroughtheaddition ofpolymer filmswhichwasultimately responsibleforimproving thetoughness and brittlenessofthefibresforfibre-reinforcedmaterials,resulting inincreasedoppositiontocracking because ofthetransferofstress from the bamboo fibre to the cement mortar(Josep *et. al.*, 2011).

Figure4.5showedcuring for45daysofsampleBledto3.6%incrementinflexural strengthmorethanthe28day strengthequally60daysstrengthhad54.1%higherstrength morethan28 daysand 48.7%strengthmorethanthe45dayscuring strength.Thispatternis alsoobservedinsamplesCandNwheresignificantimprovementinstrengthwereobserved on increasing days of curing. For composite samples with varied polymercontentand constantfibrereinforcements,mostofthemhadflexuralstrengthimprovementasthecuring daysincreased.SpecimenOhasits45thdaystrengthhaving8.5%higherflexuralstrength than28th dayresultwhilethe60th daygaveanhigherincrementinstrengthover45th day curingat15.6%.AlsosampleRhad11.4%higher strengthonthe45th day morethanthe28th day,whilethe60th dayhadflexuralstrengthof7.3%higherthanthe45th day.SpecimenY alsohasits45th daysstrength having11.4%higherstrengthabovethe28th day whilethe60th day hadanincrementof7%overthe45th dayandanimprovementof19%overthe28th day.

Inastudy byChen*et.al.,*(2017)ontheinfluenceofvariedcuring timeonthe mechanicalpropertiesofconcrete,itwasstatedthatconcretestrengthisheavilydependent on thecuring timeandthebehaviouroftheplasticdeformationandfailurestrengthisalso determinedby thecuring time.Therefore,ifthecuringdaysweretobeprolonged,itwould have anincreasedinfluence onthe deformation andfailurestrengthoftheconcrete.Thistrait ofenhancementinstrengthwassimilarlyobservedby Daniel*et.al.,*(2017)whenvariedcuring duration of7, 14, 28 and 90 days were used to investigate theeffect on anumberof mechanical characteristicsof recycled concretethat waspre-soaked.

One way ANOVA (See Appendix P for details) showedthattherearenosignificanteffectsofvarying the acrylicpolymer contentsontheflexuralstrengthpropertyofthecontrolsamplematerialsatap-valueof 0.3239. The analysis also revealed thatthereisasignificanteffectofvaryingthepolymersand using aconstantfibrecontentofthe bambooontheflexuralstrengthofthecontrolsample materialatap-valueof0.0101. The One way ANOVAsimilarly signifiesthatthereisalsoa significanteffectof varying thefibreswhile keepingtheacrylicpolymerconstantonthe flexural strength ofthecontrol sample at ap-valueof0.0251.

iii. Comparison between split tensile strength and curing duration

FromFigure4.6,thereareincreasesinsplitstrengthofthesamplesacrossthecuring duration.Forpolymeronlymodifiedsamples,Bhadincreaseinresistancetosplittingby 1 1.4%on45th daymorethan28th dayandanincreaseinstrengthat22.5%wasrecordedat the60th day morethanthe45th day. SampleChadimprovedresistanceby8.9%from28th to 45dayandanincreaseof26.8%wa sobservedfrom45th to60th day.SampleNhada progressiveincreaseinsplitstrengthof8.9%atthe45th day and27.5%atthe60th day.The optimumstrengthwasrecordedatthe60th dayforspecimenswith10%and15%polymer inclusion with inclusionof1.5%bamboo fibre.

Sampleshavingfibresandpolymershadmoreabilitytoenduretensileforces.This wasbecauseproductsofcementhydrationandlatexfilmswere developedasaresultofthe blendingbetweentheacrylicpolymerandmortar.Thus,anetworkoflatexwasformed withinthemicrostructurewhichcreatedastrongtensionwithinthetestedsamples(Baoshan *et. al*., 2010).

One way ANOVA showed that there is no significant effect of varying the acrylic polymercontentsonlyat5%,10%and15%onthesplittensilestrengthpropertyofthe controlsample materialata p-value of 0.1571.The ANOVA analysis also showedthatthere wasa significant effectof varying thepolymerswhilekeeping thebamboofibresconstantonthesplittensile strength propertyofthe control sample at ap-valueof0.0487. Therewas alsoasignificanteffectofvarying thebamboofibreswhilekeeping thepolymercontent constant on thesplit tensilestrength propertyofthe control sample atap-valueof0.05.

4.3 CrackPatternandFailure Modes ofFerrocementModifiedBamboo Columns

4.3.1. Unloadedcolumns (Control Specimens)

The initial development of the firstcrack commenced at the contact point between the concrete column and the upper plate. Linear hairline cracks located at the mid-point of the reference sample was responsible for this failure. Subsequent increase in the load resulted into the development of cracks and its propagation at zones nearer to the upper concrete column face in direct contact with the testing machine. Atabout90to95% of the ultimate load,vertical cracksbecamenoticeable.With theriseinaxial load,theamountandwidthofthesecracks begantoriseuntilthe specimengetstoitsfailurepoint.Itcouldalsobe observedthatunlike complete crushingofconcretethat was observed duringthecompressivestrength test offibre reinforced samplesearlier,the failure of the concretecolumnswas as a result of crack development, small splinters and mortar chips that were detached from the column surface. Nonetheless,most ofthe columns tested have their physical outlook showing they were okay when viewed superficially, however, on closer and thorough visual confirmation, it could be seen thatstructuralintegrity ofthe columns have been compromised seriously. This is because the center has developed multiple internal cracks which was propagated to the exterior leading to its eventual failure under load.

4.3.2. Unloadedcolumns (FerrocementJacketed Specimens)

The concrete column commenced its failure by the development of cracks beneath the jacket. The jacketed columnspecimens'failurepatternsweretriggeredby originalcrackingatthestress concentrationpointsintheferrocementjacketcausedbytheloadbeingapplied.IntheC$_{11-15}$samples,thecornerswerethefirsttoexperiencecrackingoccurredduetostress concentration.IntheP$_{11-15}$specimen,crackingoccurredatthemiddleofeachface because the roundedcornersreducedthe stressconcentration.The stressconcentrationpoints of mostcolumnsarethe pointsof curvature changes;these alsowere notedtohave some cracks.Otherspecimenshad an occurrence of cracksatbothedgesandthecentreofeachface (Plate 4.7).

4.3.3. Preloadedcolumns (repaired)

Thepreloaded but repaired columnsfailedslowly throughformationofcracksand detachmentoftheplasteredmortaronthe ferrocement mesh jacket during theprocess of its repairing atthe upper portionof the concrete column.This failure wasprogressivedownwardswhile C$_{6-10}$failure took place very close to the corners.Acontinuousfailure patternwasnoticedbecauseofthepreliminary damagecausedbythepriorapplicationof 25,50 and75% forceontheultimate load of the columns.For the entirecolumns tested,failure commencedfromthe pointofcontactwiththeloadplatenofthemachinedownwards.Thiscouldhavecaused by the intense connection provided by the metalstripsusedasa knot on the bamboo reinforcement which supplied the needed internalconfinementwithincolumns.The heightinboth typesofspecimenshadsimilarcracksand crushed levelssincethey bothpossessthesameknotting patternofthemetalstripsforallthe columns produced and tested.

4.3.4 Load– DeflectionofFerrocementRepairedBamboo Columns

Stressismostlyproducedintheinteriorpartofasystemwhenan externalforceis appliedtoabody,thiswillsubsequentlyresultinto an increasedlevelofstresswheneverthe forceisincreasedleadingeventuallytofailureofthat strength of the columns.Therefore, stress concentration occursatedgeswhen considering the traditionalsquareferrocementjacketing samples(Kaish,*et.al*.,2015).Usingthesamehypothesis,itcanbededucedthatstress concentrationisreducedattheedgeofjacketedspecimensandthestressflows

Plate 4. 7:Cracking at edges

towardsthe directionofthejacketcentre. Therefore, stress concentrationtakes place towardsthe center of the columns that were jacketed andthisledtothepeeling and bulgingofthecement mortars. A study by Cao *et. al.*.(2010) provided the reason for this situation. The results of the investigationshowedthattheconfinement methodisinfluencedbytheconfined concretewithin the region whichtransferstheperfectlyconfinedzone'sstresstopoorlyconfinedzone'sstress therebymakingthestressfrom theconfinementtobe evenlydistributed andmore effective. All ferrocementjacketedspecimensshowsuperiorultimateaxial load overcontrol specimens.Table4.4displaysthemeancriticalloadcarryingcapacityoftestedsamples. Inclusionofferrocementjacket and acrylicemulsionpolymerresultedinan incrementinthecriticalloadat$P_{11\text{-}15}$whichposted the maximumaxialload in comparison with the reference sample.

The comparisonbetweenrepairedsamples andcontrolsamples'load- axial displacement curvesare presented inTables4.5and4.6 (See Appendix Q for the graphs).Theimprovedferrocementjackettechniqueeffectson thefracturedandbrokencolumnsafterrehabilitation(repaired)showedthattheultimate deflectionand loadarein good comparison with control specimens.

Generally,therepairedcolumnsoriginalload-deflectionpatternswere retained by reason of the effectiveconfinementsuppliedby theferrocementjacket.Thisimproved strengthiscausedbythereliabilityofthecompositematerialbasedontheexistenceofa highvolumepercentage of the meshwhichsuppliedthenecessary confinement tothecoreofthe concreteaswellastheenhancementofdimensionalstability oftheconcretecolumns (Kondraivendhanand Pradhan,2009).The core ofthe columnisbombardedwithhuge confinementpressureaswellascracktransmissionredistributionwhicheventually resulted into reduced expansion laterally of the center of the concrete column.Therefore,theconfined columns samplestrengthwasdiscoveredtobe higher thanthe referencespecimens.Higher valuesof lowerdisplacement and ultimate loadwere displayedbycolumns modified with polymers afterrepairwhen compared withthatof referencesamples.This is indicative of the fact that the repair ofpartly damagedcolumnspecimenscouldassistin the recovery of theinitialstrengthandaswell asenhancethe load-deflection response.A similarobservation was madebyShuai*et. al.,*(2017) who explored theutilizedAlkali-ActivatedSlag (AAS)ferrocementin

Table 4. 4: Comparison between ultimate loads of ferrojacketed and non-ferrojacketed samples

S/N	Status	Av. Ultimate load (kN)	Av. Ultimate load	Difference of loading
1	C 1 - 5	No ferrocement	130	-
2	P 1 - 5	No ferrocement	143	10%
3	C 11 - 15	Ferrocement	190	46.2%
4	P 11 - 15	Ferrocement	210	60%

Table 4. 5: Differencein axial deflections

S/N	Specimen type	Status	Av. ultimate deflection (mm)	Difference in deflection
1	C_{6-10}	No ferrocement	3.64	-
2	P_{6-10}	No ferrocement	2.09	42% decrease
3	C_{11-15}	Ferrocement jacketed	1.66	54% decrease
4	P_{11-15}	Ferrocement jacketed	1.61	56% decrease
5	C_{6-10}	Repaired with ferrocement jacket	0.25	93% decrease
6	P_{6-10}	Repaired with ferrocement jacket	0.65	82% decrease

Table 4. 6: Differencein lateral deflections

S/N	Specimen Type	Status	UltimateAverageLateral Deflection(mm)	Differencein Lateral Deflection(%)
1	$C_{1–5}$	No Ferrocement	1.26	-
2	$P_{1–5}$	No Ferrocement	0.90	29 %decrease
3	$C_{11–15}$	Ferrocement Jacketed	0.52	59 %decrease
4	$P_{11–15}$	Ferrocement Jacketed	0.64	49 %decrease
5	$C_{6–10}$	Repaired with Ferrocement Jacket	0.46	63 %decrease
6	$P_{6–10}$	Repaired with Ferrocement Jacket	0.35	72 %decrease

the strengthening ofrustedreinforced columnsfromconcrete.In the case of the repairedspecimens,the stirrups and reinforcements were notedtobe strongerwith the confinementfromAASferrocement.The descriptive statisticsis showninTable 4.7while the p-value obtainedfromthe analysisof variance inTable 4.8is higherthan0.05,suggestingthatthetreatmentswerenotsignificantly different.Thisshows thatthe polymer-modifiedconcrete columnhasnosignificanteffectover the normalconcrete columnsbyreducingtherateofdeflectionduringthe axialloading.Tofurther establishwhetherthecontrolsamplesandtheP_{6-10} samplessignificantlydifferedinaxial deformations,TukeyHonestly SignificantDifferencetest(Tukey HSD),aposthoctest,was performed on thedata.

Theresultoftheposthoctestispresentedin Table4.9.ThecriticalTukey HSD Q-statisticsand$Q_{critical}$valuesforC_{1-5} andP_{6-10} obtainedfromtheStudentizedRange distributionbasedonthenumberoftreatments(k=2)andthedegreeoffreedom(v=4)at the significance levels $\alpha = 0.01$ and $\alpha = 0.05$were5.2431 and 3.4605respectively. The observedQ-statisticswere comparedwiththe Q-criticalfor allpairsof treatmentsandit revealedthatthe valuesof theobservedQ-statisticswere lesser thanthe valuesof the Q-critical.Theseobservationshave revealedthattheinclusionof acrylicemulsionpolymer into the columnshaslittle effectonitsresistance todeformation.Thisanalysisalsoshowedthat even thoughthe columnshadfailedbefore itwasrepairedwith ferrocement,itcould still resist axial loadingas much as theoriginal column before failure. The p-value obtainedfromtheanalysisof variance inTable4.10islower than0.05, suggesting thatthetreatmentsweresignificantly different.Thisshowedthattheferro-jacket repairedcolumnshave a significanteffectover theunloadedconventional concretecolumnsby vastly reducingtherateofdeformationduringthetestingdurationalongtheaxialdirection. Thissimilarly showedtheeffectofferrocementinrepairingcracksinconcretetoobtaina structurally stablematerial.Theferrocement jacketalsoprovidedanincreasedstrengthand stiffnesstherebycrackpropagationalong thecolumns was reduced.Tukey Honestly SignificantDifference test(TukeyHSD)wasalsoperformedonthedata.

Table 4. 7: Statistical AnalysisofAxial Deformations of TestColumnsunder StaticLoad

Specimen type	Status	Sum	Mean	Variance	Standard deviation
Control	No ferrocement	10.91	3.63	0.01	0.11
P_{6-10}	No ferrocement	6.28	2.09	0.08	0.29
C_{11-15}	Ferrocement Jacketed	4.98	1.66	0.02	0.14
P_{11-15}	Ferrocement jacketed	4.86	1.62	0.03	0.16
C_{6-10}	Repaired with ferrocement jacket	0.75	0.25	0.06	0.24
P_{6-10}	Repaired with ferrocement jacket	1.96	0.65	0.10	0.32

Table 4. 8:ANOVA plot of$C_{1-5}$and Ferro-jacket repairedP_{6-10}

Source of variation	Sum of squares	d.f.	Mean square	F-statistics	P-value
Between groups	10.0184	1	10.0184	5.7453	0.0535
Within groups	10.4628	6	1.7438		
Total	20.4810	7			

Table 4. 9: TukeyHSD Results betweenFerro-jacket repaired$C_{1-5}$and P_{6-10}

Treatment Pair	Tukey HSD $Q_{statistics}$	Tukey HSD $Q_{critical}$ 0.01	0.05	Tukey HSD P-value	Tukey HSD Inference
C_{1-5}VS P_{6-10}	3.3898	5.2431	3.4605	0.0535156	Insignificant

Table 4. 10:ANOVA plot of$C_{1-5}$and Ferro-jacket repairedC_{6-10}

Sourceof Variation	**Sumof Squares**	**d.f.**	**Mean Squares**	**F**	**Pvalue**
Betweengroups	12.9032	1	12.9032	7.6635	0.0325
Withingroups	10.1024	6	1.6837		
Total	23.0056	7			

4.3.5 Anova andTukey HSDStatistical Analysis Axial Deflections of Columns

ThecriticalTukey HSDQ-statistics and$Q_{critical}$valuesforC_{1-5}andC_{11-15}obtained fromthe StudentizedRange distributionbasedonthe numberoftreatments(k= 2)andthe degreeoffreedom(v=4)atthesignificancelevels$\alpha=0.01$and$\alpha=0.05$were5.2431and 3.4605 respectively (Table 4.11).Theobserved Q-statistics were compared withtheQ-critical forall pairs of treatmentsanditrevealedthatthe valuesofthe observedQ-statisticsweregreaterthanthe values oftheQ- critical, this indicates that thevalues aresignificant to eachother. Thisshowedthattheunloaded acrylicemulsionpolymer modifiedconcretecolumnsthatare reinforcedwithferro-jackets havesignificanteffectoverthenormalconcretecolumnsinreducing theratesof deformations alongthe axial direction duringthetestingduration. One way ANOVA analysisfor$C_{1-5}$and P_{11-15}atthesignificancelevel$\alpha=0.05$ was0.180 (Table 12),thisindicatesthatthe valuesarenotsignificanttoeach other. This showed that there is little or no improvement in strength through the dual influenceoftheincludedacrylicpolymerandtheferro-jacket on thecolumns overthecontrol samples.

The pvalue obtained fromtheanalysisofvariance between repaired and un-repaired ferrojacketed conventional columns isgreaterthan0.05 (p value was 0.1893), suggestingthat thetreatments werenot significantlydifferent.This showed that columns with littlecracksaccompaniedwithportionsoffailedsectionscanbeeasily repairedwithferro-jacketstoproducebetterandimprovedcolumnsthatcouldcompetefavourably withtheun-repairedcolumnswithoutundermining itsstructuralintegrity aslongastheloadtowhichit couldofferresistanceisnotexceeded.TukeyHonestlySignificantDifferencetest(Tukey HSD)wasalsoperformedonthedata.ThecriticalTukeyHSDQ-statistics and$Q_{critical}$ valuesforC_{1-5} andferro-jacket repaired C_{11-15}obtainedfromtheStudentizedRangedistributionbasedonthe number of treatments(k=2)andthedegreeoffreedom(v=4)atthesignificancelevels$\alpha=0.01$and$\alpha = 0.05$were 5.2431and3.4605respectively.Thisindicatesthatthe valuesare significantto eachother.Thisshowedtheprospectofusing ferro-jacketasarepairtoolinfortifyingcracks oncolumnstoproduce animprovedandresistantstructure whichwillwithstandaxial deflections.

Table 4. 11: TukeyHSD Resultsbetween Ferro-jacket repairedC_{1-5} and C_{11-15}

Treatment Pair	Tukey HSD $Q_{statistics}$	Tukey HSD $Q_{critical}$ 0.01	0.05	Tukey HSD P-value	Tukey HSD Inference
C_{1-5}VS C_{6-10}	3.9151	5.2431	3.4605	0.0324978	Significant

Table 4. 12:ANOVA plot of$C_{1-5}$and P_{11-15}

Sourceof Variation	Sumof Squares	d.f.	Mean Squares	F	Pvalue
Betweengroups	4.5829	1	4.5829	2.2992	0.180
Withingroups	11.9594	6	1.9932		
Total	16.5423	7			

4.3.6. ANOVA along LateralDeflections

FromTable4.13, it could be seen thattherearenosignificantdifferencesamongthe normal concrete columns(control),acrylicpolymer modifiedcolumnsandferro-jacketedacrylic polymermodifiedcolumns,theseshowedthatmovementalong thelateraldirection perpendiculartotheappliedloadis minimal whichatteststothestrengthofthedual improvementof boththepolymerand themeshwhich wereincorporatedinto thecolumns. However a significantdifference occurredamongconventionalconcrete ferro-jacketcolumns (C_{11-15}), repairedferro-jacketedcolumns(C_{6-10})andrepairedacrylicpolymermodified ferro-jacketedcolumns(P_{6-10}).Thismeantthatminimal deflectionsoccurredperpendicularto the applied load direction.

4.3.7 Energy Absorption

Energyabsorptioncapacity isknownastheareaundertheload-deflectiongraphtill the ultimate load. In Table 4.14, decrease in energyabsorption was noted for jacketed ferrocementspecimensincomparisontocontrolspecimenexceptP_{6-10}thisismostly because theuseofjacketspostponedthespecimens'failurebyasubstantialmarginincomparison withcontrolsamples,thereforeanimprovedbetterenergy absorbingcapacitywasobtained. Theability ofthebambooreinforcedconcretecolumnstotakeinenergybeforeitfailedis becauseofitspostcracking performancewhichtheembeddedcolumnusestodelay concrete failureanddelamination.Although,theenergy absorptionvaluesforTable4.15columns specimensare lower tothose of Table 4.14,theirreductionpercentagesare lower due tothe ductilebehaviourofthereferencespecimenwhichshowedlimitedaxial deformation.The amountofenergy expendeddependsonultimateload,firstcrackloadanddeflection.In addition,water-cementratio,fineaggregatecontentandreinforcementarrangementinthe mix seriouslyaffected thequantityofenergyneeded to causedeflection.

Table 4. 13: ANOVA forLateral Deflections ofTested Columns

Combination	$F_{statistics}$	P-value	Rating
Control and P_{6-10}	3.59	0.11	Not significant
Control and C_{11-15}	2.29	0.18	Not Significant
Control and P_{11-15}	1.34	0.29	Not significant
Control and C_{6-10}	2.54	0.61	Not Significant

Table 4. 14: Energyabsorption during axialloading

S/N	Specimen Type	Status	Energy Absorption during axialdeflection (Joules)	Differencein Energy absorption(%)
1	C_{1-5}	No Ferrocement	83.7	Nil
2	P_{1-5}	No Ferrocement	80.5	3.8 % reduction
3	C_{11-15}	Ferrocement Jacketed	54.9	34.4 % reduction
4	P_{11-15}	Ferrocement Jacketed	41.4	50.5% reduction
5	C_{6-10}	Repaired with Ferrocement Jacket	39.3	53% reduction
6	P_{6-10}	Repaired with Ferrocement Jacket	1.8	102 %increase

Table 4. 15: Energyabsorption duringlateralloading

S/N	Specimen Type	Status	Energy Absorption during lateral deflection (Joules)	DifferenceinEnergy absorption(%)
1	C_{1-5}	No Ferrocement	57.7	Nil
2	P_{1-5}	No Ferrocement	30.2	47 % reduction
3	C_{11-15}	Ferrocement Jacketed	44.7	22.5% reduction
4	P_{11-15}	Ferrocement Jacketed	50.1	13.1% reduction
5	C_{6-10}	Repaired with Ferrocement Jacket	45.6	20.9% reduction
6	P_{6-10}	Repaired with Ferrocement Jacket	41.1	28.8% reduction

4.4 Edge cracking anddelamination performanceofroof

Edgecrackingisaseriousphenomenonthatcommonly affectsaircuredfibre-cement roofcompositematerialsduringthedryingphase.Itiscaused by stressesgeneratedatthe initialagewhichoccurswhenmorerapidwaterevaporationtakesplaceintheedgethanat themiddleportionoftheroof.Lateralsideoftherooffacing theNorthgenerally hadthe highestpercentageofcracking asshownin Table4.16.Thispercentageisminimalwhen comparedto theresultsobtained byFiorelli*et. al.*,2014. This implies that thereis astrong relationshipbetweentheaverage temperature andthe rate ofwaterlossover the durationof exposuretothenaturalweather(Fiorelli*et.al*,.2014).Thisinturnisalsoclosely relatedtothe shrinkagepropertyofthecompositewhich will eventuallylead to thestressinduced cracks.

Wiremesh materialgavethe edges aserrated lookdueto portions ofit shootingout of the roofplates, this is asa result ofpoorfinishing at the edges. This could possiblyprovide an entranceformoistureduringtheyearroundandeventually causewettinganddryingcycles overtheperiod. This observation is onlylimited to the edges at this side.

However,nopropagationof crackswasobservedatthe middle andtheSouthside of theroof.Thereis verylittlecrackobservedattheSouthpartedgesofthe roofpossiblydueto the orientationof the roof asitwasinclinedatasmallangle.Thismeantthatrainfallwater wouldfalldownbygravity andnotpenetratethematerials. Alsoanotherimportantfeatureis theroletheacrylicpolymerplayedinproviding awaterresistantfilmtobridgethevoid producedashydrationofcementprogressesovertheperiodunderobservation.Similarly, edgecracksthatoccurredarequickly andpromptly arrestedatthesourceby theferro-mesh beforeitcanbepropagatedtootherlocationsatthemiddleoftheroof.Moreover,therewas no identification of anyincidenceofdelaminationofthe roofingpanels under consideration.

4.5 Acceleratedageing

After 50cyclesof acceleratedageing,itwasseeninTables4.17 – 4.20 (See Appendix R for the ANOVA analysis of dimensional stability) that significantincrementinMORandMOEtookplace.SampleAafteracceleratedageing test showedanimprovementof33.3%inMORand 135%inMOEresults. SampleB hadan improvementof64%inMORand85%inMOE,sampleCincreased by 71%inMORvalues and101%inMOEresultsandlastlysampleDindicatedsignificantimprovementof57%and 188%afteracceleratedageing tests.Theimprovementinthemechanicalstrengthcouldhave beencausedbythemodificationofthematrixbytheacrylicpolymer.Theseleadtoincrease infibreandmatrixbondingbecause ofintermingling ofthecementhydratesandthepolymer films.These productswere able toblockthe developmentof voidsandspacesleadingtothis improvement.

Anotherreasonadducedtothisasreportedby Tonoli*et.al.,*(2009)whoalsoreported increasein strength aftertheageingtests, was that improved densification and continuation of cementhydrationduring theageing testscausedthepropertiesofthecompositestobe improved. Tonoli*et.al.,*(2013) alsoremarked thatMOR of fibrereinforcedcementcomposites increasedsignificantlyafter200cyclesofageingtestsduetothereductionofvoidsatthe fibre matrixinterface because ofreprecipitationof cementhydrationproductsintothe voids. Soroushian*et.al.,*(1994)furtherconfirmedthisphenomenonintheirstudiesby affirmingthat mineralizationeffect whichistheprecipitation ofcementhydrationproductswithinthe naturalfibrecenter andatthe densificationatthe interface causedthe improvedstrengthof naturalfibre cementcomposites.Inconfirmationof the previousresultsdiscussed,sample C with1.5%bamboofibreand10%acrylic polymercontenthadthe best performance forboth theMORandMOEresults.Itcouldbeseenthatbeyond1.5%fibreinclusion,thevaluesof the mechanical properties reduced; therefore the maximum fibre content should be maintainedinordertoproduceadurableandstructurally safebuildingcomponent.Similarly, Table4.20showstheeffectof acceleratedageing onthedimensionalstability properties.

Itwasobservedthatasthe fibresincreased,therewasincrease inthe waterabsorption andthicknessswelling ofthecomposites.Acceleratedageing testshadsignificanteffectson thedimensionalstabilityofthecementcompositesbecauseof moisturemigrationintothe cellwallsandtheinterface.Thisledtoirreversiblecyclicswellinganddryingofthecell walls which eventually affected the stability of the specimens especially the thickness swellingandwaterabsorption.

Table 4. 16: Proportion (%) ofobserved cracks onNorth and South faces atdifferentages

Face/age	**N1**	**S1**	**N2**	**S2**	**N3**	**S3**	**N4**	**S4**
28 days	0	0	0	0	0	0	0	0
3 months	0	0	0	0	0	0	0	0
6 months	0	0	0	0	0	0	0	0
9 months	0	0	0	0	0	0	0	o
12 months	02	0	02	0	05	01	07	02
15 months	03	01	05	03	12	07	13	09
24 months	04	02	06	05	17	11	15	13

Table 4. 17: Acceleratedageing effect on bending tests

Composites	28 days MOR (N/mm^2)	28 days MOE (N/mm^2)	50 cycles MOR (N/mm^2)	50 cycles MOE (N/mm^2)
A	2.1	491.5	2.8	1159.2
B	2.2	809.7	3.6	1502.9
C	2.4	877.6	4.1	1759.6
D	2.1	457.9	3.3	1317.9

Table 4. 18: OnewayANOVA ofaccelerated ageing effect on MOR tests

	Sumof Squares	**Degrees of freedom**	**Mean Square**	**F-statistics**	**Pvalue (0.05)**
Betweengroups	18.1673	7	2.59	2.50	0.04
Withingroups	28.0202	27	1.03		
Total	46.1874	34			

Table 4. 19: OnewayANOVA ofaccelerated ageing effect on MOE tests

	Sumof Squares	**Degrees of freedom**	**Mean Square**	**F-statistics**	**Pvalue (0.05)**	**Inference**
Betweengroups	$6.9e^{6}$	7	$9.8e^{5}$	2.84	0.02	Significant
Withingroups	$9.3e^{6}$	27	$3.4e^{5}$			
Total	$16.2e^{6}$	34				

Table 4. 20: Accelerated ageing effect on dimensional stabilitytests

Composites	24hrs WA (%)	24 hrTS(%)	50 cycles WA (%)	50 cycles TS (%)
A	0.6	0.02	0.8	0.06
B	1.8	0.35	2.1	0.44
C	2.4	0.54	2.6	0.60
D	2.9	0.81	3.0	0.85

4.6 Comparative cost of roofing sheet

The summary of the comparative cost analysis between the produced roofing sheet utilizing the developed building material in this study is shown in Table 4.21 while the detailed information is presented in APPENDIX. The unit cost of the bamboo reinforced acrylic polymer ferrocement modified roofing sheets was 10% cheaper than the conventional and commonly used galvanized roofing sheets available locally in the market

Table 4.21: Comparative cost of roofing sheets

Roofing sheets	**Cost/m^2**	**Price comparison**
Modified bamboo sheets	1161.00	Reference
Galvanized iron sheets	1300.00	11% more than reference

CHAPTERFIVE

5.0 CONCLUSIONSAND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were drawn from this study:

(1) The properties of bamboo reinforced cement composite with 10% acrylic polymer addition were enhanced.

(2).Fibres and acrylic polymer helped in bridging cracks and reducing voids in the bricks.

(3) Ferrocement jacketing successfully repaired cracked and damaged bamboo columns.

(4) Ferrocement jacketing and acrylic polymer addition successfully prevented edge cracks and delamination in the roofing material.

(4). Accelerated ageing had no significant negative effect on dimensional stability and strength properties of the roofing material.

5.2 Recommendations

Furtherstudies should be conducted in the following areas:

a) The long-termdurabilityofbamboo fibrereinforcedacrylicpolymermodifiedcementcomposites.Thesuggestedstudy shouldcoverfibre degradationdegreeby analyzingsurface morphology, crystallinity index,andthermalcharacteristicsofthefibersby usingX-raydiffraction, thermogravimetricanalysis (TGA) and SEM analysis.

b) Fireresistanceofthebamboofibrereinforced polymer modifiedcomposites.Thisisessentialifthe developedmaterial wouldbe usedasastructuralmemberin reallifeapplications.Another reasonisthat bromine featuredinsome of the elementalcompositionsof the composites.Basedon the reportof some authorswhichstatedthatbromine ispartof the chemicalsthatare used in theproduction offire extinguishers, hencethis suggestion.

5.3 Contributions to knowledge

This project has madecontributions to knowledgein the followingareas:

a)Abuilding materialwithimprovedpropertieshasbeendeveloped.Theproduct formulationandoptimumconditionsnecessary forproducingacceptablecomposites have been identified.

b)Characterizationofcompositesfrombamboofibres,polymermodifiedmortar and ferrocementintermsof strength,microstructure,elementalcompositions,andthermal performancehave beenestablished.

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