PERFORMANCE EVALUATION OF CONCRETE CONTAINING CASSAVA PEEL AS SUPPLEMENTARY CEMENTITIOUS MATERIAL (SCM) ASH AND BAMBOO AS REINFORCEMENT

BY

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DECLARATION

I Oluwasegun James ALADEGBOYE an M.Eng student in the Department of Civil Engineering, Landmark University Omu-Aran, hereby declare that this thesis entitled PERFORMANCE EVALUATION OF CONCRETE CONTAINING CASSAVA PEEL AS SUPPLEMENTARY CEMENTITIOUS MATERIAL (SCM) ASH AND BAMBOO AS REINFORCEMENT submitted by me is based on my original work. I further declare that this project or its contentment has not been anteriorly submitted to this or any other institution of learning to consummate the requisites for the award of any degree. All citations and sources of information and research are pellucidly acknowledged using references.

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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirements of the Department of Civil Engineering, Landmark University, Omu-Aran, Nigeria, for the Award Master Degree.

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ABSTRACT

The major materials utilized in construction activities is reinforced concrete which contains steel and cement. Emission of carbon-dioxide and the depletion of the air quality index can be attributed to the production of cement and steel. There is limited information on the performance of concrete containing cassava peel ash (CPA) and bamboo as most work has always been on concrete and steel. Therefore, this research aims to evaluate the performance of concrete containing cassava peel ash (CPA) and bamboo

One hundred and seventy-four samples of beams and cubes were produced from twenty-nine experimental runs of bamboo reinforced concrete (BRC) containing CPA. Four variables namely CPA content, bamboo size, beam length and beam depth were used to evaluate the compressive strength, flexural strength and flexural strain of the CPA and BRC. The addition of the CPA varied from 0 to 20 % while the bamboo size varied from 12 to 16 mm. The beam length varied from 400 to 600 mm while the depth of bamboo beam varied from 150 to 250 mm respectively. Data was analyzed using descriptive statistics and Response Surface Methodology (RSM)

The CPA and compressive strength values for the concrete were 0, 10, 20 % and 23.4, 22.2, 21.4 N/mm^2 respectively. The values obtained for the flexural strength of concrete were 6, 10 and 12 N/mm^2 for bamboo sizes of 12, 14, and 16 mm respectively. The values for the flexural strain for CPA of 0, 10, 20 % were1.0, 0.5 and 0.0 % respectively. The results obtained ranged from 307.9, 322.0 and 393.3 N/mm^2 for 12, 14 and 16 mm respectively for tensile strength of bamboo.

The concrete mix met the requirement for grade 20 which is used in most cases for structural concrete work. The bamboo size and length of the beam also affected the performance of bamboo reinforced concrete positively. The CPA values were inversely proportional to the compressive strength values. It is therefore recommended that casava peel ash should be used as replacement for cement up to 20 % while bamboo can be used as a replacement for steel in structural elements such as beams, columns and slabs.

DEDICATION

This research is dedicated to the giver of life and wisdom, for His love, faithfulness and guidance throughout my study time. Also, to my jewels and princesses: Olayemi, Flourish, Dominion and Blossom. And to the ones whose brief earthly appearances are the reason I am here; Mr. S. and Mrs. A. Aladegboye; continue to rest with Jesus Christ till we meet to part no more.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Concrete can be defined as a combination of four or more materials such as coarse aggregate, fine aggregate, cement and water with good compressive strength but low tensile strength and elasticity. This deficiency of concrete is taken care of by the introduction of reinforcement with good tensile strength or ductility. The reinforcement is conventionally, but may not be steel is usually arranged in the formwork before the concrete is poured. Steel reinforced concrete has been one of the most outstanding addition in the construction industry since its introduction in the 19th century (Gupta, 2013). Concrete has exceptional qualities that make it the most acceptable construction material in the world. Concrete has remarkable compressive strength and is sound with low maintenance requirements, and can be produced in various sizes and shapes (McCormack and Brown, 2014). Green concrete is plastic in nature which enables it to be poured into already prepared formwork which can be of any shape, this makes it better than any other materials (Muxing, 2015). Concrete is a popular material in construction for public works and it has good compressive strength and durability. The composite material named concrete since inception has undergone several evolutions and would continue to evolve as long as new inventions are discovered. It will continue to undergo changes ranging from its constituent materials, mixing, strength, application and maintenance. This is so, especially as sustainability is now a key issue in concrete production. It is therefore important to focus on the changes that the construction industries will have to implement to make concrete produced more sustainable (Aitcin and Mindess, 2011). Various types of waste have been introduced in concrete to ensure sustainability. (Thomas *et al*., 2014; Jnyanendra and Sanjaya, 2015; Maddalena *et al*., 2018).

The use of these other materials in concrete production such as supplementary cementitious materials (SCM) produced from agro-based ash and other materials always result in alteration of properties of concrete produced if materials were conventional. In addition, the adoption of bamboo as reinforcement in concrete has been advocated based on research findings. To ensure that the structure is safe however, when these materials are used there is a need to carry out performance evaluation of reinforced concrete produced.

The use of SCMs in suitable proportions and combinations in concrete is increasingly becoming inevitable as they provide technical, economic and environmental advantages. These advantages result from the reduction in clinker consumption and enhanced utilization of agricultural/industrial by-products (Erdem and Kirca, 2008). The use of multi blends (composed of Portland cement with one or more SCMs) is being normalized following the new trends in cement development.

The most popular SCMs used in concrete are blast furnace slag (BFS), fly ash (FA), limestone powder (LSP), rice husk ash (RHA), silica fume, natural pozzolan and metakaolin (Ofuyatan *et al*., 2018). Rice husk ash (RHA), sugarcane straw ash (SSA) and groundnut husk ash (GHA) have been used by some notable researchers as pozzolan in concrete (Frías *et al*., 2007), Cizer *et al*., (2006) and Ketkukah and Ndububa (2006)). The use of these ashes has been observed to improve the workability of green concrete (Ofuyatan *et al*., 2018).

In recent times, the attention of researchers has been drawn to cassava peel ash (CPA) due to its abundant availability in this part of the world. Cassava peels are obtained from the peeling of cassava tubers and it makes up twenty to thirty-five per cent of the tuber mostly during the process of manually removing the peels (Adesanya *et al.,* 2008). The generation of CP rose to about twelve million tonnes in the year 2020 (Raheem *et al.*, 2015). The unethical disposal of cassava peels which is resulted from under exploitation and lack of adequate means to manage them has become a challenge and this has caused serious environmental pollution. In view of the foregoing, the search for a better way of management has become critical. Cassava peels calcined at 700^{o}c for ninety minutes have been experimented and the results showed high pozzolanic potentials and it also meets the minimum requirements of seventy per cent combine oxide of silicon, aluminium and iron (Salau and Olonade, 2011).

Moreover, concrete has little or no tensile strength which inform the introduction of steel to reinforce the concrete. The ever-increasing cost of steel and the need for sustainability has led to the search for alternatives and bamboo fits into this category due to its high tensile strength and renewable nature. Bamboo has become a reliable replacement for steel in structural element construction (Schneider, *et al.*, 2014).

Shheider *et al.*, (2014) investigate bamboo reinforced concrete beams under force loading, during the testing the stress flexural cracks were seen to be at a very low level of loading which occured below twenty per cent of the design maximum strength. The formation of early crack is due to the modulus of elasticity of bamboo that is lower than that of concrete and is within the range of 14000-16000 N/mm^2 which depends on the compressive strength. (Schneider, *et al.*, 2014; Janseen, 2000).The tensile strength of bamboo have been investigated and was found to be as high as 370 N/mm^2 (Bashir, *et al.*, 2018). With this, bamboo has become a viable replacement for steel in tensile loading application and this is as a result of the ratio of tensile strength to unit weight of bamboo that is six times higher than that of steel. (Amada, *et al.*, 1997).

In Nigeria, one of the basic needs of people which have frequently remained unsatisfied is adequate shelter. The incorporation of bamboo as a locally made construction material for use in low-cost residential buildings is likely to increase the chances that Nigerians hoping to own houses may do so. Falade *et al* (2002) discovered that bamboo is a better and cheaper substitute for steel in beams and columns in low-cost houses and as it had comparative advantages over steel reinforcement. It is not susceptible to corrosion; it absorbs water and has a high Fibre content. It is cheaper and locally sourced. It is cost-effective while its inclusion in concrete beams increases the load-carrying capacity of the beam in low-cost houses. It was identified that the use of bamboo would reduce the cost of reinforcement by 30 per cent depending on design, location of the site and other variables (Rosulu *et al*, 2020).

The mix proportioning of constituent materials in concrete plays a vital role in achieving the required targeted properties hence the design of experiment (DOE) using software packages such as response surface methodology (RSM), Taguchi designs, designs for the second-order model, optimal designs, mixture designs etc. for mix proportioning is necessary. The DOE gives the relationship between independent variables (experimental conditions) and the dependent variables or responses (outcome of the experiments) using the minimal number of experiments and provides improved processing, by the optimization of inputs to obtain the best output. They can be applied in different fields of industry such as Engineering, Biotechnology, Marketing and Advertising etc. (Myers and Montgomery, 2002, Cihan *et al.*, 2013).

The Response Surface Methodology is a powerful analytical tool for designing experiments, prototyping, assessing components' impacts, and finding the best conditions (Alyamac *et al*, 2017; Mohammed *et al*., 2018;). Various components that operate concurrently are fitted to a quadratic function in RSM. RSM outperforms the one factor at a time method, which is slow and ignores the interrelationships between factors (Esfahanian et al., 2013). RSM balances the constituent materials to achieve the best mix proportion, which is then utilized as a mathematical model to anticipate the desired attributes (Hasan *et al*; 2007).

It is therefore worthwhile for this study to predict the flexural strength and flexural strain of bamboo reinforced concrete containing locally available SCM (CPA). This study explored the potential of the depth of beam as one of the factors in predicting the above-mentioned properties as well as percentage cement replacement, length of beam and bamboo size using Response Surface Methodology. In addition, the study also examines the effect of CPA as SCM on the green and hardened properties of concrete.

1.2 Statement of Problem

An average Nigerian is most likely to erect a bungalow as shelter and steel will be required as reinforcement for short span beams and columns. But steel as reinforcement materials is becoming very expensive and unaffordable for an average Nigerian who may desire to build due to lack of viable steel manufacturing company. This has made us largely dependent on importation to meet the rising demand for steel and this has led to the rising cost of steel. Today Nigeria turns out 0.11% of global steel (less than two million metric tons) but imports 5 million tons yearly (Britannia Encyclopedia, 2020). This research focuses on finding an alternative to steel with the use of bamboo as reinforcement due to its sustainable and renewable nature.

Upon 14 million tons of cassava peel generated annually and the Government's poor way of handling waste coupled with inadequate landfills to accommodate the waste generated from cassava, it has become imperative to find alternative use of this waste that is beneficial to man and the environment which is the focus of this research and this informed the use of CPA as SCM in this research.

1.3 Justification

A lot of work has been done on using agro-based materials as a partial replacement for cement and bamboo as reinforcement but this research focuses on using the RSM for predicting and optimization to evaluate the performance of the concrete containing SCM and bamboo.

The use of agro-based materials such as CPA as SCM and bamboo as a replacement for conventional steel reinforcing material will help to achieve the sustainable development goal (SDG) 11 and 13.

1.4 Aim and Objectives of the Study

The purpose of this research is to properly assess the performance of concrete containing cassava peel ash as SCM and bamboo as replacement for steel

The specific objectives of the study are to:

i. Determine the tensile strength of bamboo as a replacement for steel in concrete.
ii. Determine the chemical and physical properties of CPA used as SCM.
iii. Examine the fresh and hardened properties of concrete containing CPA and bamboo.
iv. RSM can be used to figure out how different parameters (bamboo size, beam depth, beam length, and percentage cassava peel ash (CPA)) affect the physical and mechanical properties of bamboo reinforced concrete (flexural strength and flexural strain).

1.5 Significance of Study

The technologies used in the field of RCC construction have not been changed since the time steel in the form of reinforcement was introduced and codes were developed to use it in various conditions and several ways in load-bearing structural members. The reason behind this trend is surely the immense strength of steel but for smaller structures, where low strength is required as compared to the high rise structures to tackle self-weight as well as the loads that amount to a huge magnitude because of numerous floors. The structures that are not meant to be put under loads of high magnitudes can be built with an alternative of steel that can bear loads up to certain limits safely and cheaper, easily available and eco-friendly.

The major reason for the choice of bamboo is its Carbon-absorbing property while it grows, so instead of emitting CO_2, unlike steel, while it is in the stages of growing, it would absorb it. It will also help in reducing the self-weight of the structure thereby ensuring the sustainability of the construction industry, reducing environmental pollution and depletion of the ozone layer which is the target of SDG 11and 13.

1.6 Scope of Work

This study and the extent of it would be confined to achieving the specific objectives as it has been listed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concrete

Despite the usefulness of concrete in construction, a lot of people are not familiar with its features, especially its preparation, flexibility and durability (Gupta, 2012). Concrete is a hard, strong building material made up of sand, gravel, cement, and water. It is primarily workable before it becomes solidified and can remain strong over long time scales. It is used to construct structures such as buildings, roads, bridges, vessels, pipes, drainage, and other structures. The earliest concrete was discovered in Israel in 1985 during road construction that dates back to around 7,000 BC. Among the well-known concrete structures are Pompeii's theatre, Rome's Colosseum and Pantheon, and France's Pont du Gard Aqueduct.

Concrete is made up of fine aggregate (sand), coarse aggregate (gravel/stones), and water, as well as a binding agent (usually cement), to hold the other components together. A normal mix contains 7-15 per cent cement, 14-21 per cent water, and the remainder aggregate (Gupta, 2011). The water-cement ratio (W/C) of the mixture determines the concrete's final qualities. The weight of water in relation to cement in a combination is referred to as the water-cement ratio. Civil engineers use the water-cement ratio (W/C ratio) to make decisions. The engineer can control two desirable attributes using the W/C ratio: strength and workability. The water-cement ratio (W/C) of the mixture determines the concrete's final output. The water-cement ratio refers to the amount of water in a mixture in relation to the amount of cement. The water-cement ratio (W/C ratio) is a determining factor for civil engineers. Engineers can control two desirable attributes using the W/C ratio: strength and workability. (Somayaji, 2001).

W/C's value varies from 0.6 to 0.65 since it offers great workability without sacrificing much strength (Gupta, 2011).

2.2 Agro-Based SCM

Because the cost of cement, which is used as a binder in the creation of mortar, is rising, sandcrete blocks are becoming more popular, sandcrete bricks, and concrete, researchers are looking for alternative binding agents. Besides costs, high energy demand and CO2 emissions that lead to global warming – the depletion of limestone reserves – is one of the disadvantages of cement production. Badur and Rao (2008) report that cement production emits roughly 7% CO2, which has a detrimental impact on the environment and human future due to global warming (Badur *et al.,* 2008). So far, research on cement alternatives has focused on partial cement replacement with various materials. Partially replacing cement with pozzolan has been widely studied and suggested in advanced countries (Badur et al., 2008, Neville, 1996). In its report (ACI 232.1R-00), the American Concrete Institute defines pozzolanic material as "siliceous and aluminous material, which has little or no cementitious value in itself but will chemically react with calcium hydroxide at ordinary temperatures to form compounds with cementitious properties when finely divided and in the presence of moisture." Pozzolan, as defined by Arthanari *et al*. (1981), is a siliceous substance that has no cementitious capabilities by itself but, when processed and finely divided, reacts with lime in the presence of water to generate low-solubility compounds with cementitious qualities.

Naturally occurring pozzolans include clay and shale that has been calcined to become active, volcanic tuff, and pumicite, whereas artificial pozzolans include good blast furnace slag and fly ash. In advanced countries, fly ash, a byproduct of pulverized coal combustion, is recommended as a partial replacement for cement in the range of 10-30% by weight of cement. (Arthanari *et al.,* 1981). OPC is currently being discussed, not only because of its expense, but also because of the environmental impact of its manufacturing. To produce one ton of OPC, 1.5 tons of quarry material, 5.6 Gj/Ton of energy, and around 0.9 Ton of CO2 are required, accounting for 5% of global human CO2 emissions. (Reddy et al., 2006; O'Rourke et al., 2009; Juenger et al., 2011; Billong et al., 2011; Billong et al., 2011).

Other pozzolanic-based Alternative Hydraulic Binders (AHB) are being developed at the moment. Pozzolanic cement is a mixture of Portland cement and pozzolanic material that has the following properties: strong chemical resistance, low heat of hydration evolution, economy, improved workability, reduced bleeding, and increased impermeability. Slower strength growth and greater shrinking are two of its drawbacks (Seeley, 1993). Agro-based wastes are the most prevalent and widely available material in underdeveloped nations that can be utilized to partially replace cement without causing economic harm.

Low capital cost per tonnage production compared to cement, low-cost waste management, reduced pollution from these wastes, and increased farmer economy base when such waste is sold, thereby encouraging more production are some of the advantages to be gained from using agro-waste in the partial replacement of cement, as presented by Dashan et al., 1999 and Alabadan et al., 2000. (2005). Pozzolanic materials were widely employed in ancient civilizations. Many constructions created with lime–pozzolan mortars and concrete are still surviving today. In recent years, pozzolan-cement mixtures have been used to construct high-rise buildings, motorways, dams, bridges, harbours, canals, aqueducts, and sewer systems throughout Europe and the United States. Researchers like Ketkukah and Ndububa have employed ashes from rice husks, sugar cane straw, and groundnut husks as pozzolan in concrete (2006). They discovered that adding these ashes to concrete improves both its compressive strength and its workability. Rice husk ash has been shown to minimize alkali-silica reactivity and drying shrinkage in prior studies. The performance of these materials as pozzolans, according to Nehdiet al. (2003) and Mehta and Monteiro (2004), is determined by the kind and amount of amorphous silica component, which is further determined by the calcination temperature and time. Rice husk ash should be burned at 650°C for 60 minutes, according to Ramezanianpour et al. (2009), while sugar cane straw ash should be burned at 800°C to 1000°C.

2.3. Cassava peel ash

Cassava peel (CP) is a waste product from the cassava processing industry that can be used both in the home and in the industry. Cassava peel contributes 20-35 per cent of the tuber's weight, according to Adesanya et al. (2008), especially when hand peeling. 6.8 million tons of cassava peel are produced annually, according to a 20% projection, with 12 million tons expected in 2020. Cassava peels are tossed indiscriminately due to significant underutilization and a lack of recycling equipment, providing a huge challenge and causing environmental problems. As a result, alternative methods of recycling materials are required (cassava peels).

Agricultural waste, such as corn cob ash and cassava peel ash, is becoming increasingly popular (Adesanya and Raheem, 2009; Olushola and Umoh, 2012 and 2014). Cassava is a well-known carbohydrate source, with Africa producing the most. The tubers are peeled, and the skin is discarded as solid trash. As the industrial production of cassava goods like as cassava flour and "gari" expands, these wastes will become even more problematic.

Salau and Olonade (2011) explored the pozzolanic potential of cassava peel ash (CPA), discovering that it has pozzolanic properties when calcined at 700C for 90 minutes. Under these conditions, CPA had more than 70% combined silica, alumina, and ferric oxide.

2.4. Steel Reinforced Concrete

The compressive strength of steel-reinforced concrete is high, but the tensile strength is low. Concrete is blended with another material that has a high tensile strength to be used as a construction material. Combining or reinforcing concrete with steel is the oldest and most used approach (Linda, 2016). Concrete and steel interact in reinforced concrete structures so that the concrete can absorb compressive stresses and the steel can absorb tensile forces. Brittle failure, which occurs suddenly and without warning, is the most common cause of concrete failure (Linda, 2016). Steel is more ductile than other metals. Concrete and steel combine to make a composite material that can withstand bigger deformations before breaking.

Because concrete's tensile strength is low, an unreinforced piece will break when the concrete's tensile strength is achieved. (Linda, 2016). Steel bars are placed in the tensile zone to meet the high compression strength in concrete. To get the most out of composite materials, concrete, and steel, the force transfers between the materials must be effective. This is accomplished by a strong bond between the materials. Bonding involves several mechanisms, including adhesion between cement paste and steel, friction between steel bars and concrete, and bonding at the interface between steel bars and the roughness of the concrete (Isaksson, et al., 2010). It is critical to have adequate concrete cover when employing steel bars to reinforce concrete. The thickness of the concrete cover is critical for corrosion protection, fire resistance, and cracking resistance. A minimum cover thickness of 30 mm is standard for a steel-reinforced concrete element.

2.5 Bamboo as Reinforcement Material

Bamboo is the world's fastest-growing plant (Alfonso, 1987); the botanical literature lists around 70 genera and 1000 species (Anon., 1988). They favour sandy topsoil over loamy muck soils and flourish in subtropical and temperate regions. It's a plant with a short growth cycle and a lot of flexibility. Bamboo culms grow at a rapid rate, averaging 70 millimetres per day on average and up to 350–450 millimetres per day in extreme circumstances. Depending on the species, the development of its culms takes 4–6 months, and the maturation takes 2–6 years (Wong, 1995). Bamboo culms are usually smooth and cylindrical, with diameters ranging from 29 to 300 mm. Bamboo wood contains 60–70% fibre, which is more visible on the outside than the inside (Wong, 1995). On average, bamboo reaches a height of 100 times its diameter. Bamboo has a distinctive growth pattern that includes aspects of grass, leafy tree, and palm. Tubular blades, lanced-shaped cover leaves, and odd grass-like blooms distinguish them. Bamboo has a solid foundation and is continually expanding its crown. Every year, it loses its leaves (Atanda, 2015).

Bamboo is a perennial evergreen grass family that includes the largest members of the grass family, the Poaceae. It's an old woody grass that grows in tropical, subtropical, and temperate climates (Hunter, 2003; Akayode *et. al*. 2016). A monocotyledon perennial herbaceous gigantic woody stem plant with an above-ground structure of culms, branches, and leaves and a below-ground structure of rhizomes and roots (Rosulu et al, 2020). The towering vertical rods called culms, which are generally hollow but are separated into portions by a solid rib or node, are the most conspicuous feature of the bamboo plant. Inter-node refers to the space between two nodes.

Most bamboo species have branches, and this one sprouted on the node. Rhizomes develop horizontally underground in the root. Each plant has a plethora of rhizomes that branch underground and develop new shoots and roots at the node. Bamboo may grow to a height of 30 meters and a diameter of 30 centimetres (Rosulu *et al*, 2020).

Bamboo comes in two varieties. There's a lot of clumping and running going on. They are categorized based on their root system and growth characteristics. The rhizomes of running bamboo develop horizontally underground, with new shoots emerging up to 3 meters away from the mother plant. Because it is an invasive plant that spreads swiftly, this species is typically found in bamboo forests. Clumping bamboo, on the other hand, has rhizomes that grow out and up from the plant's base, creating new shoots close to the older ones. Because of the intense multiplication of culms and ease of care, they are especially valuable in plantations (Rosulu *et al*, 2020).

Bamboo grows to full maturity in a matter of months and achieves maximum mechanical strength in a matter of years. It is a cost-effective material because of its abundance in tropical and subtropical locations. It is a good construction material because of its lightweight design, improved flexibility, and toughness due to its thin walls with discretely scattered nodes, as well as its great strength. Bamboo is a durable, flexible, lightweight, and low-cost material that is utilized as a structural material for scaffolding at construction sites in India, China, and other nations. When bamboo is blanketed in snow, it bends till it reaches the ground without breaking. Bamboo, on the other hand, has a greater flexibility than wood. The energy necessary to produce 1 m3 per unit stress for bamboo was compared to the energy required to produce 1 m3 per unit tension for common civil building materials like steel or concrete. Steel consumes 50 times more energy than bamboo, according to a research. Bamboo has a high tensile strength, which can approach 370 MPa at times. As a result, bamboo can be used in tensile loading applications instead of steel. Bamboo's tensile strength-to-specific-weight ratio is six times that of steel, which explains why. (Ghavami, 1995).

2.5.1 Applications of bamboo

Bamboo is employed for a wide range of purposes, including recreation, defence, housing, and construction. Bamboo can also be consumed, in addition to being utilized in the arts. In recent years, the demand for bamboo shoots has exploded. Taiwan exports $50 million worth of shoots, which are consumed all over the world (Leena, 2005). Building and housing are two of the most common uses for bamboo. Bamboo dwellings are believed to be home to one billion people. Bamboo is utilized in the construction of temporary suspension bridges in India and China. In Tokyo and Hong Kong, Bamboo is used to build temporary suspension bridges. It is utilized in high-rise structures in Tokyo and Hong Kong as scaffolding (2004, Ghavami). Furniture, decorative objects such as home décor (Figure 2.1), dishware, dolls, toys, jewellery, and other items are only a few examples. The artist's imagination is limitless, as is the artist's imagination as shown in Figures 2.2(a) and (b).

Figure. 2.1 Bamboo flooring (Anon., 2015).

Figure 2.2a Bamboo Bicycle (Ghavami, 2005).

Figure 2.2b Bamboo Street Sweeper (Ghavami, 2005).

Bamboo fishing poles have long been used to catch fish, making them a popular instrument for obtaining sustenance.. It would also make a good spear shaft. Bamboo is becoming more popular as a flooring and panelling material in the United States. Ply-boo is a company that makes bamboo plywood. Bamboo has also been used in some parts of the globe as a full replacement for steel in building and bridge construction but is most popular in India as shown in Figure 2.3.

Figure 2.3: Bamboo as replacement for steel in slab, beam and column construction (Online Image)

2.5.2 Characteristics of Bamboo

Bamboo is not a tree, but rather a big grass. Bamboo culms (Figure 2.2) are cylindrical shells with solid transversal diaphragms at nodes. They feature interesting properties including strong strength parallel to the fibres that run longitudinally throughout the length of the culm and low strength perpendicular to the fibres. The density of fibres in the cross-section of a bamboo shell varies with thickness and height. At the bottom, the distribution of fibres is more uniform than at the top or centre. This is because the upper portion of the culm experiences the most bending force as a result of wind (Ghavami, 2004).

Bamboo is a natural Functionally Graded Material (FGM). It has a hierarchical structure and is a composite. Bamboo has a higher tensile strength than other wood products. The feature of a whole bamboo column and variation in thickness, diameter and intermodal length is shown in Figure 2.4a and Figure 2.4b

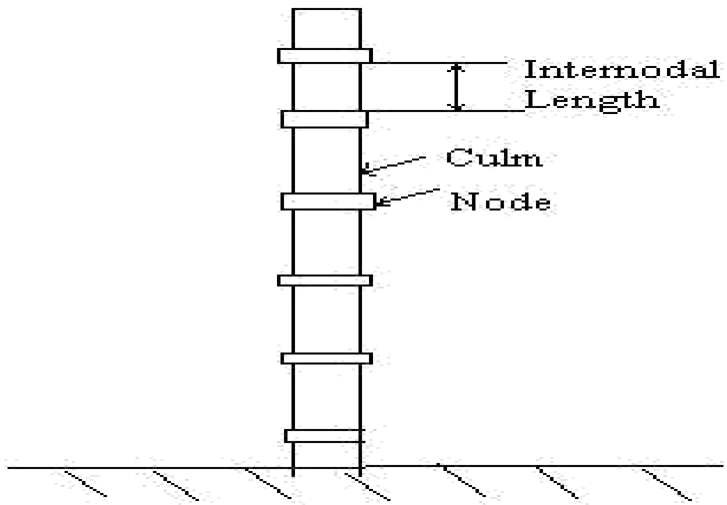


Figure 2.4a: Schematic Diagram of Whole Bamboo Culms (Ghavami, 1995).

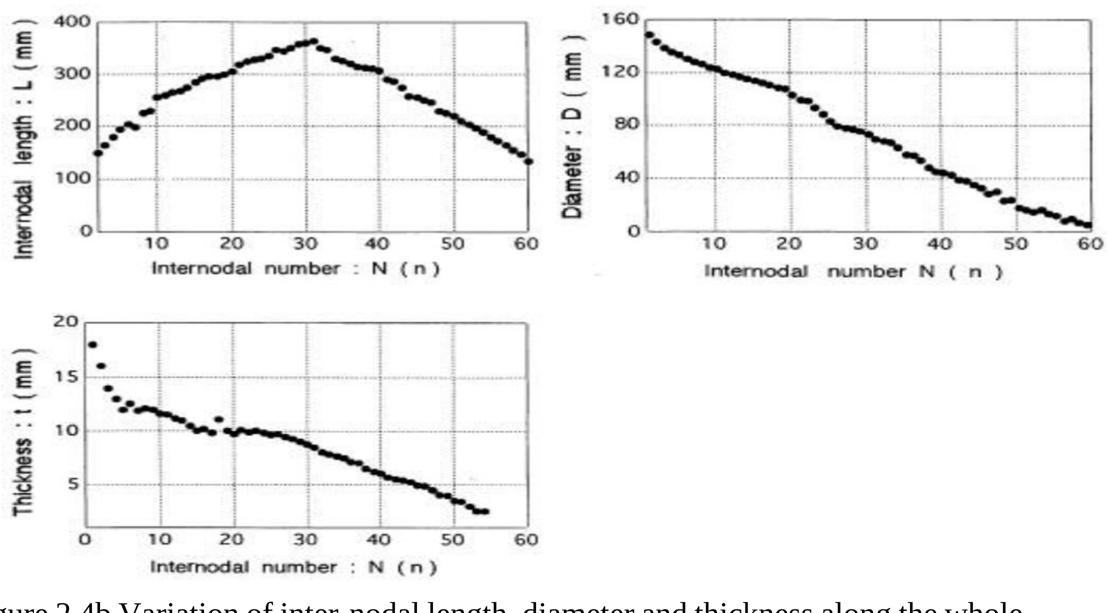


Figure 2.4b Variation of inter-nodal length, diameter and thickness along the whole bamboo culms (Ghavami, 1995).

The mechanical qualities of bamboo culms change with their height and age. The strength of bamboo appears to improve with age, according to research. Between the ages of 2.5 and 4, a child's strength reaches its peak, after which it gradually declines (Amada *et al.*, 2001). The nodes serve as axial crack arresters and prevent buckling.
One of the most significant disadvantages of bamboo is that it is a living biological substance prone to fungal and insect infestations. Due to its high nutritional content, bamboo is more vulnerable to insect attack than other trees and plants. To remedy this issue, bamboo must be treated to protect it from the elements. The way bamboo interacts with other plants is one of the most fascinating elements of the plant. Bamboo has been found to help reduce pollution by absorbing huge amounts of nitrogen from wastewater and lowering carbon dioxide levels in the atmosphere. (Steinfield, 2001).

2.5.3 Previous Works on Bamboo

Ghavami (2005), Agarwal *et al*. (2014), and Sevalia *et al.* (2013) all proved the need of providing at least minimal bamboo reinforcement as well as an adequate surface treatment to improve the binding. Ghavami (2014) discovered that beams reinforced with 3% split bamboo had four times the ultimate capacity of equivalent unreinforced concrete beams. The authors of the latter two investigations claim that bamboo-reinforced concrete with no bond augmentation splints and a reinforcing ratio of around 1.4 per cent performs no better than unreinforced concrete.

Bamboo can be used as a steel reinforcement substitute when compared to ordinary concrete or steel-reinforced concrete when subjected to irregular cycle loads (Lakshmipathy and Sanathakumar, 1980). According to Alade and Olutoge, the typical strength of bamboo is between 204 and 250 N/mm2, equal to mild steel (2004). The diameter of the reinforcement has an impact on tensile strength; ordinary steel reinforcement does not have similar effects. Bamboo has a tensile strength of 28,000 per square inch, whereas steel has a tensile strength of 23,000, making it a strong choice for earthquake structural engineering. (Andam, 1995).

Bhalla et al. (2008) used an environmentally friendly material called "Bamcrete" to construct a shed with a 5 m height and a 10 m span, utilizing DG bamboo as the straight component and Ferro cement as the batten element. Different cross-sections were employed to design various elements, such as columns, bamboo bow beams for roof support, purlins, and so on. The frame was then examined for various load combinations. The experimental results were examined and validated using STAAD Pro. Chauhan (2012) designed the bamboo shed and its components (base plate and foundation). The test results showed that various substances, such as tube tyre rubber and Araldite, increase the friction capability of bamboo.

The shear and compressive strength of two bamboo species were investigated by Kajjam *et al*. (2012). (Dendraucalamus Strictus, DS and Bamboo Pallida, BP). DS has a stronger compressive strength than BP. The shear strength of split bamboo was tested using bamboo half splits as battens on two types of samples: single hole and double hole. The strength of a double hole was 14.376 MPa, which is significantly greater than the strength of a single hole. The fabrication of a single column using two columns of two different species (DS and BP) was accomplished by integrating them with clamps and using half split bamboo pieces as a batten. Finally, at Trinity College Dublin, a compressive load test was performed on a built-up column (TCD). The stress-strain relationship for the columns was investigated, and it was determined that the load capacity of the BP column was 17.5kN and that of the DS column was 21kN.

The tensile and compressive strengths of two Dendraucalamus Strictus species were tested by Bhalla *et al*. (2013). (Giant Bamboo or Dragon Bamboo). The dragon bamboo is red, whereas the huge bamboo is black. Both bamboo species originated in Assam. The black Giant Bamboo had a compressive strength of 64 MPa and the red had a compressive strength of 45 MPa, while the tensile strength was 76 MPa and 62 MPa, respectively. The researchers also looked at the relationship between bamboo strength and moisture content. The strength was shown to be decreased the higher the moisture content. Bhagwat (2017) investigated various designs for fibre reinforced bamboo composites (FRBC). Different elements of a structure, such as a column, beam, portal frame, and joints, were tested under varying stresses. They had demonstrated appropriate behaviour and weight carrying capacity.

2.6 Response Surface Methodology (RSM)

For changing levels of direct variables on predicted outcome, RSM incorporates the use of linear, reaction, and quadritic terms, which is used when correct optimization is required. It investigates the link between the answer and the factors, as well as which element had the greatest influence on the process (Fjodorova and Novic, 2015). RSM has been used in many different engineering research projects. RSM can be used to locate reaction surfaces and develop a ready-to-use mix design for producing concrete that meets certain requirements (Cau and Courtois, 2003; Grabiec and Piasta, 2004; Mandal and Roy, 2006; Nambiar and Ramamurthy, 2006).

RSM has cutting-edge strategies for dealing with complex experimental designs. It can primarily be used in situations when specific characteristics have a substantial role in predicting a system's behaviour (Maran et al., 2013). Experiment design, modelling, and optimization are the three main processes (Myers and Montgomery, 2002). The experimental design entails proportioning the constituent materials to produce an optimal mix proportion that may be utilized as a mathematical model to anticipate desired features (Hasan and Kabir, 2011). Response surface methodology (RSM), Taguchi designs, designs for second-order models, optimal designs, mixture designs, and other software tools are required for mix proportioning.

The DOE enables improved processing by optimizing inputs to produce the optimum output by determining the dependencies between experimental circumstances (independent variables) and the results of the experiments (dependent variables or responses) using the fewest possible experiments. They're useful in a variety of industries, including engineering, biotechnology, marketing, and advertising (Myers and Montgomery, 2002; Taguchi et al., 2004; Cihan et al., 2013).

2.6.1 Application of RSM

Although the use of RSM in concrete is relatively recent, experimenters like Alsanusi and Bentaher (2015) used it to forecast the compressive strength of traditional concrete and discovered the impact of mixed elements on concrete strength. RSM was used to propose and build two mathematical models for predicting concrete compressive strength after 28 days.

RSM was used by Awolusi *et al.,* (2019) to anticipate and improve the characteristics of steel-concrete mixes. Limestone powder is injected into the fibre derived from used tires. The study used independent variables such as aspect ratio (50–140), water-cement ratio (0.2–0.4), and cement content (25–40%), while limestone powder was kept constant at 5% by weight of concrete. The study finds out that the mathematical models offered are capable of forecasting the required fresh and hardened properties of Fibre-reinforced concrete in order to aid in early construction decision-making.

Box and Liu illustrated the use of RSM on a standard training example of paper helicopters (1999). Box was able to trace RSM's beginnings (1999). Furthermore, the research established a broader idea of sequential learning, of which RSM is a component.

Kowalski (2002) included split-plot studies into the development of robust parameters. He created 24-run designs in two ways: partially folding a 16-run design and utilizing the characteristics of a balanced incomplete block design. The designs can estimate all significant effects and almost all two-factor interactions when only a few noise variables and a few design elements are present. The designs are meant to provide a middle ground between 16 and 32 run screening.

Research Gap

After thorough review of literatures, it was observed that there was no information on using any SCM with bamboo and no one has subjected their work to performance evaluation using Response Surface Methodology (RSM) which makes this investigation a timely one as its focused on using RSM tool to evaluate the performance of CPA as SCM and bamboo as replacement for steel.

CHAPTER THREE

RESEARCH METHOD

3.0 Introduction

This chapter explains in detail how the research was carried out in order to meet the study's objectives. It includes the numerous materials utilized, the techniques for testing these items to guarantee quality assurance and control, and the many laboratory tests that were conducted.

3.1 Materials

3.1.1 Portland Limestone Cements (PLCs)

The Dangote brand of Portland limestone cement (with grade 42.5) sourced from a cement store in Omu-aran was used.

3.1.2 Aggregates

Sharp sand was employed as the fine aggregate in this study, and it came from Omu-aran, Kwara State. The fine aggregate used in this project was cleaned to remove any silt or clay impurities and sun-dried (Figure 3.1). The particle size ranges from 0.15 to 1.18 millimeters. Coarse aggregates have a diameter greater than 4.75 mm but generally range between 4.75 mm to 12.5 mm. It was also discovered in a quarry off Oko Road in Omu-aran, Kwara State. It was angular and well-shaped, with fine stone dust sparingly scattered throughout. The sieve analysis was done and presented in Figure 3.2

Figure 3.1 Sun drying the washed sand

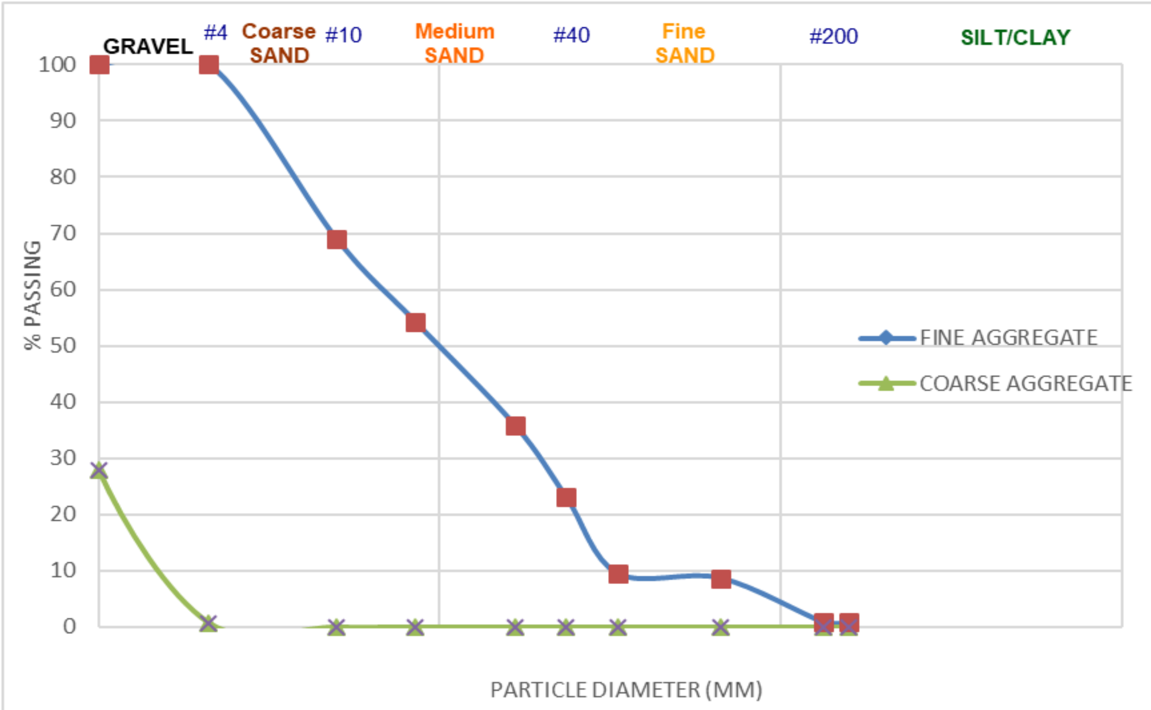


Figure 3.2: Sieve Analysis for fine and coarse aggregate

3.1.3 Cassava Peel Ash

The cassava peel was collected from Landmark University farms and Omu-Aran town, Irepodun Local Government of Kwara State. The peel was sun-dried and calcined at 800°C for two hours using a Thermolyne furnace at Agricultural Science Department, Landmark University Omu-Aran (Figure 3.3 A and B). The ashe were first sieved (Figure 3.3 C and D) and then further pulverized to required level of finer particles with ball milling machine at the Geotechnical Laboratory of Civil Engineering Department and allowed to pass through sieve number 200 (75µm).

Figure 3.3 A: Sun drying of the cassava peels

Figure 3.3 B: Sieving of the ash

3.1.4 Reinforcement

The Bamboo used as a replacement for steel was sourced in Omu-Aran and its environs after which it was processed into a round shape of diameter sizes 12mm, 14mm and 16mm at the wood workshop of Civil Engineering Department, Landmark University (Figure 3.4a and 3.4b). The bamboo was also treated with bitumen in order to ensure proper bonding with concrete and to prevent moisture (Figure 3.5a and 5b).

A B

Figure 3.4: Processing of bamboo

A B

Figure 3.5: Coating of bamboo with bitumen

3.1.5 Water

Potable water sourced from LMU laboratory was used for the preparation and curing of concrete.

3.2 Experimental Design

The tests were carried out using a Box-Behnken Design (BBD) with four components at three levels, as shown in Table 3.1. The % ash, bamboo size, depth of the beam, and length of the beam were chosen as the input factors (independent variables) for the optimization. $N = 2k (k - 1) + Co$ is the number of experiments required to produce BBD (where k is number of factors and Co is the number of central point). There are 29 runs in all, with 5 central points in the experimental design.

Table 3.1: Experimental Design Layout

Test No	% Ash	Bamboo size	Depth (mm)	Length (mm)
1	10	14	200	500
2	10	14	200	500
3	10	14	200	500
4	10	14	150	400
5	10	14	250	400
6	20	12	200	500
7	10	12	200	400
8	10	12	150	500
9	10	14	250	600
10	10	14	200	500
11	10	16	200	600
12	10	14	150	600
13	10	12	250	500
14	10	16	200	400
15	0	12	200	500
16	0	14	200	600
17	20	14	200	600
18	10	16	150	500
19	10	12	200	600
20	20	14	150	500
21	10	16	250	500
22	20	16	200	500
23	0	14	200	400
24	20	14	250	500
25	0	14	150	500
26	0	14	250	500
27	20	14	200	400
28	0	16	200	500
29	10	14	200	500

The percentage CPA addition to replace cement varied between 0-20 per cent while the bamboo size, beam depth and length varied between 12-16 mm, 150-250 mm and 400-600 mm respectively. The spacing of the reinforcement for the bamboo was 75 mm as presented in Figure 3.6.

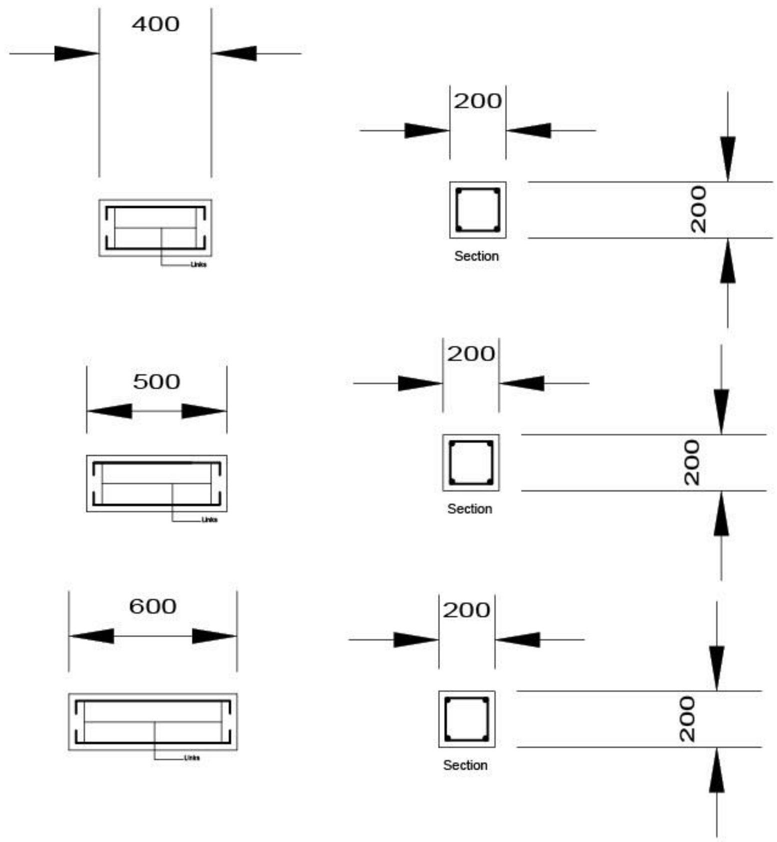


Figure 3.6: Arrangement of bamboo in the concrete.

The research included some necessary tests carried out on fine aggregates, coarse aggregates, cement, green and hardened concrete and these are tabulated in Table 3.2

Table 3.2: Tests carried out

MATERIALS	TESTS TO BE CARRIED OUT	STANDARD TEST METHOD
FINE AGGREGATES	Specific gravity test Particle size distribution Natural moisture content Silt/Clay Content Bulk density test	ASTM D854-14 ASTM C136/136M-19 ASTM D2216-19 BS 882, IS 2386-2 ASTM D6683-19
	Aggregate crushing value test	ASTM C131/C131M-20

COARSE AGGREGATES	Specific gravity test Bulk density test Aggregate impact value test Flakiness Index Test Elongation Index Test	ASTM D854-14 ASTM C29/C29M-17a ASTM D5874-16, 95 ASTM C127, AASHTO T85 ASTM C127, AASHTO T85
CEMENT	Consistency test Initial setting time test Final setting time test Soundness test Fineness test	ASTM C187-11 ASTM C403/C403M-16 ASTM C403/C403M-16 ASTM C189-49, C88/C88M-18 ASTM C430-17, C786/C786M-17
CASSAVA PEEL ASH	Fineness test Specific gravity test Sieve analysis ASTM Bulk density X-ray fluorescence(XRF) test	ASTM C430-17 ASTM D854-14 C136/136M-19 ASTM D6683-19 ASTM D5381-93
BAMBOO	Water absorption test Tensile strength test	ASTM D570 ASTM D3039
FRESH CONCRETE	Slump test Compacting factor test	ASTM C143/C143M-20 BS 1881 Part 103, ASTM 1849/C1849M-17
HARDENED CONCRETE	Compressive strength test Bulk density test Flexural strength test Crack width measurement Water absorption	ASTM C39/C39M ASTM C29/C29M-17a ASTM C78 ASTM ASTM C1585

3.3 TESTS ON MATERIALS

3.3.1 Tests on Fine Aggregates

Tests carried out on fine aggregates include:

Specific Gravity Test

The specific gravity of a material is the weight of certain volume of material per unit weight of equal volume of water (The Constructor, 2016). This test on fine aggregates was carried out to determine the ratio between the weight of a given volume of the fine aggregates and weight of an equal volume of water in accordance with (BS 882, 1992)

The specific gravity of a soil sample is calculated thus with the formulae below;

$$Specific\ gravity\ (G_s) = \frac{M_2 - M_1}{((M_2 - M_1) - (M_3 - M_4))} \quad (3.1)$$

Particle Size Distribution

The percentages by weight of boulders, gravel, sand, silt, and clay in soil samples are commonly used to indicate the particle size distribution. The soil sample was prepared according to the processes outlined in British Standard 1377-1990. The results were plotted on a semi-logarithmic scale and the uniformity coefficient and the curvature were calculated to determine the grading and packing of the soil samples respectively.

This test is carried out on the soil sample to enable its classification.

$$\%\ retained = \frac{weight\ retained}{total\ wt\ of\ sample} \times 100 \quad (3.2)$$

$$\%\ passing = \frac{total\ wt\ of\ sample - cummulative\ wt\ retained}{total\ wt\ of\ sample} \times 100 \quad (3.3)$$

Natural Moisture Content

The amount of water in the soils is measured by natural moisture content. The water content is the ratio of the mass of "pore" or "free" water in a particular mass of soil to the mass of dry soil solids, expressed as a percentage (Reddy, 2016). The soil sample was prepared according to the procedures outlined in BS 812: PART 109, 1990.The moisture content of a soil sample was calculated thus with the formulae below;

$$Moisture\ content = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (3.4)$$

Silt/Clay Content

The silt/clay content of the fine aggregates is the volume of silt/clay present in fines. Fine aggregates with larger volume of clay required washing before use in construction as silts; clay and organic matters are not suitable for construction. The silt/clay content of the aggregate was thereafter calculated with the formulae below;

$$\% \, Silt \mid Clay Content = \frac{height \; of \; silt}{total \; height \; of \; sample} = \frac{W_2 - W_1}{W_1} \times 100 \qquad (3.5)$$

Bulk Density Test

Bulk density of aggregates is the mass of aggregates required to fill the container of a unit volume after aggregates were batched (Engineering Intro, 2012). This was done in accordance to ASTM C29 (2003).

The Bulk Density of soil is the ratio of the total mass of the soil to the total volume of the same.

$$Bulk \; Density = \frac{weight \; of \; sample}{volume \; of \; ring} = \frac{W_S}{V_r} \qquad (3.6)$$

$$Weight \; of \; sample \; (W_s) = W_2 - W_1 0. \qquad (3.7)$$

$$Volume \; of \; ring \; \left(V_r \right) = Volume \; of \; cylinder = \pi r^2 h \qquad (3.8)$$

Table 3.3 shows the results of test done on fine aggregate.

Table 3.3: Fine Aggregate Test Result

S/N	PARAMETERS	VALUES OBTAINED
1	Specific Gravity	2.67
2	Moisture Content	5.48%
3	Silt/Clay Content	7.10%
4	Bulk Density	1749.33Kg/m^3

3.3.2 Tests on Coarse Aggregates

Tests to be carried out on coarse aggregates include:

Aggregate Crushing Value (Acv) Test

This is used to evaluate the resistance of aggregates to gradual increasing compressive load. The aggregate crushing test can be used to determine the strength of coarse aggregates. The aggregate crushing value (ACV) is a measure of an aggregate's resistance to crushing when subjected to progressively applied stress.

The value of aggregate crushing is calculated using the BS 812–112 standard (1990). The aggregate crushing value (ACV) for each specimen can be determined and represented as a percentage to the first decimal place using the equation below.

$$AIV = \frac{M_2}{M_1} \times 100 \qquad (3.9)$$

Where;

M_1 is the total mass of the test specimen in gram

M_2 is the mass of the material passing the 2.36mm sieve in grams

Specific gravity test

The specific gravity test on coarse aggregates is to determine the ratio between the weight of a given volume of the coarse aggregates and the weight of an equal volume of water (The Constructor, 2016). The test was done in accordance with AASHTO T 85-10. The specific gravity was calculated from;

$$Specific\ gravity\ (G_s) = \frac{M_2 - M_1}{((M_2 - M_1) - (M_3 - M_4))} \qquad (3.10)$$

Where;

M_1 is the mass of glass jar with lid (g)

M_2 is the mass glass jar with lid and sample (g)

$M_3$is the mass of glass jar with lid and water and sample (g)

M_4 is the mass of glass with lid and water (g)

Bulk density test

After aggregates have been batched based on volume, bulk density is the quantity of aggregates required to fill a container of a unit volume. (Engineering Intro, 2012). This test was also performed on the coarse aggregate. It was done in a weighted cylindrical metal of radius 5 cm and height of 11.8 cm. The cylinder was filled with the coarse aggregate in three (3) layers, each layer was given 25 blows. The weight of the aggregate in the cylinder was determined and recorded as weight "W" in kg. The cylinder divided by its volume gave the bulk density

$$Bulk\ Density\ (kg / m^3) = \frac{W}{V} \qquad (3.11)$$

Where;

W is the net weight of the aggregate and V is the volume of the cylinder

Aggregate impact value (AIV) test

The aggregates' resilience to sudden impact is determined by this test. Crushing and impact tests can be used to assess the strength of coarse aggregate. The Aggregate Impact Value (AIV) is a measure of an aggregate's resistance to shock or impact. The test was performed according to ASTM C127, and the results can be estimated using the equation below.

$$AIV = \frac{M_2}{M_1} \times 100$$

Where,

M_1 is the total mass of the test specimen in gram

M_2 is the mass of the material passing the 2.36mm sieve in grams

Flakiness and Elongation Test

The percentage of particles whose least dimension (thickness) is less than three-fifths (0.6times) of their mean dimension is the Flakiness Index of aggregates. Sizes smaller than 6.3mm are not eligible for this test. The fraction of particles in an aggregate whose largest dimension (length) is higher than nine-fifths (1.8 times) of their mean dimension is called the Elongation index.

Flakiness Index = $(X_1 + X_2 + \ldots..) / (W_1 + W_2 + \ldots.) \times 100$

Elongation Index = $(Y_1 + Y_2 + \ldots) / (W_1 + W_2 + \ldots.) \times 100$

The result of the test carried on coarse aggregate is as presented in Table 3.4 and it can be seen that all fall within standard specify values.

Table 3.4: Coarse Aggregate Test Results

S/N	TEST CARRIED OUT	VALUE OBTAIN	STANDARD VALUE
1	Aggregate crushing value test	9.51	45% Maximum
2	Specific gravity test	2.93	2.5 – 3.0
3	Bulk density test	1737.3 kg/m^3	1200-1750 kg/m^3
4	Aggregate impact value test	10.11	30% Maximum
5	Flakiness Index Test	26.2	30% Maximum
6	Elongation Index Test	26.7	30% Maximum

3.3.3 Tests on Cement

Tests carried out on the cement were in accordance with BS 4550: Part 3 (1978) and these include:

Consistency Test

This test was carried out on Dangote types of cement used during the project.

The initial setting time, final setting time, and le Chatelier soundness test must all be determined using neat cement paste of a specified consistency. As a result, for any specific cement, the water content that will form a paste of standard consistency must be determined. The vicat apparatus, which measures the depth of penetration of a needle, determines consistency. When the penetration of a plunger attached to a Vicat device is 33-35 mm, the paste is said to be of standard consistency. The standard paste's moisture content is expressed as a percentage of the powdered cement weight. Between 26 to 33 percent is considered typical.

$$Water\ content\ (\%) = \frac{mass\ of\ water\ (g)}{mass\ of\ cement\ (g)} \times 100 \quad (3.13)$$

Initial and Final Setting Time Test

This was carried out to determine the beginning of noticeable stiffening in the cement paste (initial setting) and the time at which the final hardening occur (Final setting). The time from the beginning of hydration to the final set is the setting time of the cement. Checks were also made on the cements for false and flash sets.

The stiffening of the cement paste is referred to as setting time. The initial and final setting periods are divided into two (2) segments.

The moment when the sample can no longer be properly mixed, completed, or compacted is called the initial set time (represented by a vicat needle penetration of 5mm) while the time it takes for the cement to harden enough to support a load (represented by no penetration of vicat needle) is called time of final set.

Soundness Test

The ability of cement to withstand volume expansion is referred to as soundness. In the soundness test, specimens of hardened cement paste were boiled for a set amount of time to speed up and identify any propensity to expand. The “Le Chatelier apparatus,” which consists of a tiny metal cylinder split along its generatix, was used to conduct the soundness test. In this apparatus, two indicators with pointed ends are mounted to the cylinder on either side of the split. In this procedure, the gap widening induced by cement expansion is drastically exaggerated and easily observed.

Fineness Test

The degree of grinding of the cement powder which is the fineness of cement determines the rate of hydration, the finer the cement, the faster the strength development (Suryakanta, 2013Cement fineness was determined by screening it through a standard sieve. As a result, the proportion of cement with grain sizes bigger than the specified mesh size is calculated. The sieve method which is one of the methods for testing cement fineness was used for this project; this involves sieving some cement samples for 15 minutes with the sieve BS No 170 (0.09mm). The percentage weight retained on the sieve was noted and recorded.

$$Fineness\ (\%) = \%\ weight\ of\ residue = \frac{mass\ of\ sample\ retained\ (g)}{total\ mass\ of\ sample\ (g)} \leq 10\%$$

The result of the test carried on cement is as presented in Table 3.5 and it can be seen that all falls within standard values specified in the industry.

Table 3.5: Cement Test Result

S/N	PARAMETERS	VALUES OBTAINED
1	Consistency	0.6%
2	Soundness	4.8%
3	Fineness	16%
4	Initial Setting Time	10 mins
5	Final Setting Time	635mins

3.3.4 Tests Carried out on CPA

Chemical Composition

This test was done in line with the test procedure provided in ASTM D5381-93 and it is to determine the various compound present in the ash. Such compound includes SiO_2,

Al_2O_2, Fe_2O_2 etc. The test was done at National Steel Raw Materials Exploration Agency Rabah Road, Malali Kaduna State.

ii. Specific Gravity Test

The specific gravity of a material is the weight of the certain volume of material per unit weight of equal volume of water (The Constructor, 2016). This test on fine aggregates was carried out to determine the ratio between the weight of a given volume of the fine aggregates and weight of an equal volume of water in accordance to (BS 882, 1992)

$$Specific\ gravity\ (G_s) = \frac{M_2 - M_1}{\left(\left(M_2 - M_1 \right) - (M_3 - M_4) \right)} \tag{3.1}$$

Fineness Test

The degree of grinding of the cement powder which is the fineness of cement determines the rate of hydration, the finer the cement, the faster the strength development (Suryakanta, 2013). Fineness is measured by sieving it on standard sieve. The weight of cement retained on the standard sieve was recorded.

The sieve method which is one of the methods for testing cement fineness was used for this project; this involves sieving some cement samples for 15 minutes with the sieve BS No 170 (0.09mm). The percentage weight retained on the sieve was noted and recorded. The fineness modulus can therefore be calculated using equation 3.14.

$$Fineness\ (\%) = \%\ weight\ of\ residue = \frac{mass\ of\ sample\ retained\ (g)}{total\ mass\ of\ sample\ (g)} \leq 10\% \tag{3.14}$$

3.3.4 Test Carried out on Bamboo

Water absorption

Water absorption test was carried out on the bamboo reinforcement before and after bitumen coating in order to determine the effectiveness of bitumen coating. The test was done by first taking the weight of each coated and coated bamboo stick after which they were fully immersed in a bucket of water as shown in Figure 3.7. The weight of each of six sticks was taken and record for 2hrs, 4hrs, 6hrs, 8hrs and 24hrs respectively.

Figure 3.7: Water Absorption test on bamboo

Tensile strength test

The tensile strength test was carried out on the bamboo to determine its strength and ductility as a replacement for steel reinforcement. It was done at the Strength of Material Laboratory in Mechanical Engineering Department Landmark University.

It was done in accordance with ASTM D2915 (2003) and the testing process is as shown in Figure 3.8.

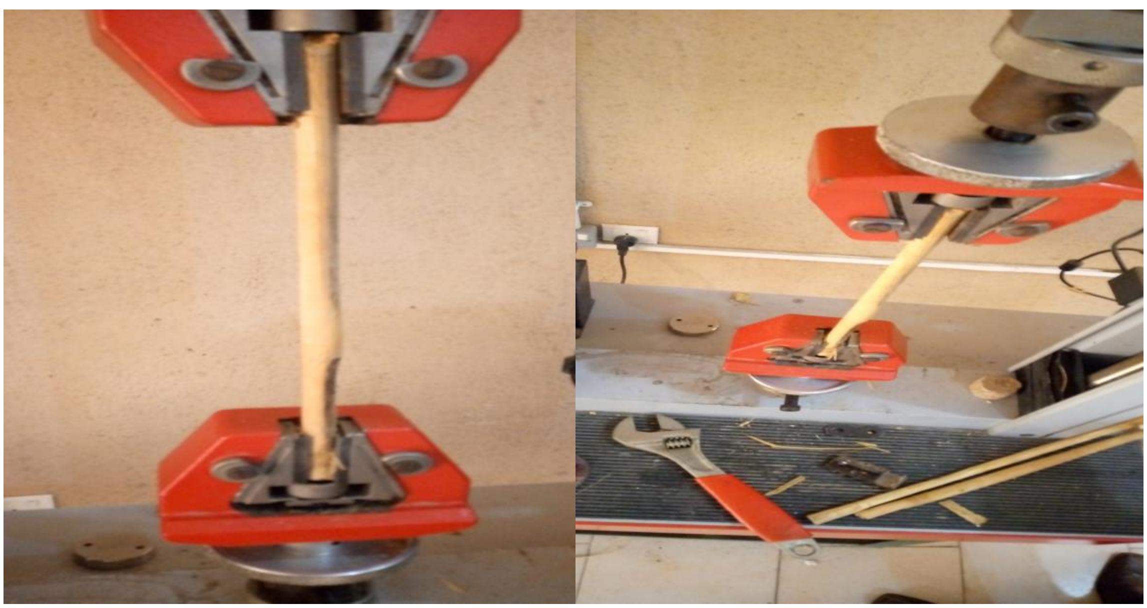


Figure 3.8: Tensile Testing of Bamboo

3.4 Batching and Mixing

The batching used in this research was by weight as it gives a more reliable mix and eradicate error. Table 3.6 shows the batched materials.

Table 3.6 Batching of Materials

Test No	PLC (kg)	CPA (kg)	RS1 (kg) (0.15-0.6mm)	RS2 (kg) (0.6-1.18mm)	CA (kg) 0-10mm)	w/c Ratio
1	14.4	1.6	16.4	4.7	14.1	8.8
2	14.4	1.6	16.4	4.7	14.1	8.8
3	14.4	1.6	16.4	4.7	14.1	8.8
4	8.6	1.0	9.9	2.8	8.4	5.3
5	14.4	1.6	16.4	4.7	14.1	8.8
6	12.8	3.2	16.4	4.7	14.1	8.8
7	11.5	1.3	13.1	3.8	11.3	7.0
8	10.8	1.2	12.3	3.5	10.6	6.6
9	21.6	2.4	24.6	7.0	21.1	13.2
10	14.4	1.6	16.4	4.7	14.1	8.8
11	17.3	1.9	19.7	5.6	16.9	10.6
12	13.0	1.4	14.8	4.2	12.7	7.9
13	18.0	2.0	20.5	5.9	17.6	11.0
14	11.5	1.3	13.1	3.8	11.3	7.0
15	16.0	0.0	16.4	4.7	14.1	8.8
16	19.2	0.0	19.7	5.6	16.9	10.6
17	15.4	3.8	19.7	5.6	16.9	10.6
18	10.8	1.2	12.3	3.5	10.6	6.6
19	17.3	1.9	19.7	5.6	16.9	10.6
20	9.6	2.4	12.3	3.5	10.6	6.6
21	18.0	2.0	20.5	5.9	17.6	11.0
22	12.8	3.2	16.4	4.7	14.1	8.8
23	12.8	0.0	13.1	3.8	11.3	7.0

24	16.0	4.0	20.5	5.9	17.6	11.0
25	12.0	0.0	12.3	3.5	10.6	6.6
26	20.0	0.0	20.5	5.9	17.6	11.0
27	10.2	2.6	13.1	3.8	11.3	7.0
28	16.0	0.0	16.4	4.7	14.1	8.8
29	14.4	1.6	16.4	4.7	14.1	8.8

Batching in concrete production is concerned with the measurement of materials for a concrete mix either by weight or volume. Materials used in this project were batched by weight according to the required mix design as in Table 3.6. The mix contains two types of fine aggregate which are RS1 (0.15-0.6mm) and RS2 (0.6-1.18mm).

The mixing process involves mixing the constituents materials after batching to enable proper hydration and also prevent segregation of aggregates. After proper mixing have been achieved, the concrete was poured into the beams and cubes mould respectively

The total number of samples cast for cubes and beams was two hundred and sixty-one each. This was subdivided into three (3) samples for each of the curing periods of 28 days for the twenty-nine (29) runs. The samples produced were cured after they have been demoulded.

3.5 Tests on Fresh Concrete

Tests carried out on the fresh concrete included:

Slump Test

The flow characteristics of fresh concrete were measured using the concrete slump test. The test is an empirical evaluation of fresh concrete's workability. It assesses uniformity between batches, to be more explicit (About Civil, 2016).

The test was conducted using a 300-mm-high concrete cone with a 203-mm-diameter open base and a 102-mm-diameter top opening. The cone was filled in three equal levels with fresh concrete, each of which was tampered with 25 times with a tamping rod. The cone was then carefully lifted, and the difference in concrete height measured from the centre in comparison with the height of the cone is the slump of the concrete as shown in figure 3.9a-d

To determine the concrete mix's workability, or how easily it can be compacted in place. The slump is done according to ASTM C143-1992 in the US, IS: 1199 – 1959 in India, and EN 12350-2 in Europe.

A B

Figure 3.9a-b: Slump test for different percentages of CPA

C D

Figure 3.9c-d: Slump test for different percentages of CPA

Compacting Factor Test

This is also to determine the workability of the concrete and the compact ability of a given concrete mix, and this will give us an idea of the strength and the quality of the concrete mix. It uses the compacting factor equipment which comprises upper and lower hoppers for evaluating the flow of the concrete. The test is done according to BS 1881-103, 5075. The compacting factor can be determined using equation below:

$$Compacting\ Factor = \frac{Weight\ of\ partially\ compacted\ concrete}{Weight\ of\ fully\ compacted\ concrete}$$

3.6 Curing of Concrete Cubes and Beams

Curing was done according to BS 1881: part 3 (1970), after 24 hours of hardening, concrete cubes were gently removed from the steel cube moulds and properly cured to allow them attain their full strength. The method of curing used was water submerged curing, in which the concrete cubes were submerged in water. This involves placing the concrete cubes and beams in a curing tank filled with water and leaving them immersed in water tank for a period of 28days respectively at a room temperature of 25ºC (figure 3.10). After each stage of curing, necessary tests were carried out in after 28 days.

Figure 3.10: Curing in progress

3.5 Tests on Hardened Concrete

Tests carried out on hardened concrete included:

Bulk Density Test

This is a measure of mass per unit volume of the hardened concrete cube. The mass is measured using the weighing balance and the volume is determined by its dimensions.

$$Volume = Length \times Width \times Height \qquad (3.15)$$

$$Density\ (kg/m^3) = \frac{Weight\ of\ cube}{Volume\ of\ cube} \qquad (3.16)$$

Water Absorption Test

The test technique, according to ASTM C-140, involves drying a specimen to a constant weight, weighing it, submerging it in water for a certain amount of time, and weighing it again. The weight difference expressed as a percentage of the original weight is called absorption (in per cent). The absorption of the test samples as a whole must not exceed 5%, with no single unit surpassing 7%.**Compressive Strength Test**

The cube specimens were weighed on the balance scale to determine their weights, after which each was placed under the crushing machine. The machine was operated hydraulically making use of electricity after the load was set to zero on the digital readout until the cube fails as the reading stopped increasing. The reading of the load was recorded at the point when the cube failed. The crushing load was expressed in Newton (N). The following formulae are used in calculating the density compressive strength of the concrete;

$$Compressive\ stregnth\ (N/mm^2) = \frac{Crushing\ load\ (N)}{Area\ of\ cube\ (mm^2)} \qquad (3.17)$$

Flexural Strength Test

The tensile strength of concrete is measured in several ways, one of which is flexural strength. A reinforced concrete beam or slab can withstand bending failure (Jayant & Gupta, 2014). The ultimate flexural strength, also known as the modulus of rupture, is a function of the highest load that may be applied. Rectangular beams were employed in this test, which followed the BS EN 12390-5:2009 criteria and used the centre point loading method. During the test, the development of the first fracture and subsequent cracking up to failure were thoroughly monitored. Once the specimen failed the maximum load shown at the display was recorded, then the distance between the crack line and the nearest support was measured and recorded as shown in Figures 3.11a and 3.11b

Modulus of Rupture f_b *(N/mm^2)* $= \frac{3Pl}{2bd^2}$ (3.18)

Where *P = maximum load (N)*

L = distance between supporting rollers (mm)

b = width of beam (mm)

d = depth of beam (mm)

Figure 3.11a: Crushing of beams and cubes

Figure 3.11b: Crushing of beams and cubes

CRACKS WIDTH MEASUREMENT

The measurement of the crack width was carried out using digital Vernier Caliper and this was recorded in millimetres. The centre crack was measured after each of the beams were loaded to failure.

Pictoral details of the tests conducted and the entire process are attached as appendix A.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter provides analyses of the experimental work. The interpretation of results obtained from work done on the effect percentage of CPA replacement on the slump, compressive strength, water absorption, bulk density and crack width, and CPA, size of bamboo, length of beam and depth of beam on the flexural strength and flexural strain has been explained in this section.

The

4.1 Results of Tests on Bamboo Reinforcement

4.1.**1 Water Absorption Test Result**

Figure 4.1 presented the results of the water absorption test done on coated and non-coated bamboo in order to validate the functionality of the bitumen coating. From the result obtained, the bitumen coating was found to be very effective as the rate of water absorption reduces greatly after the coating. The water absorption for non-coated bamboo increases from 21.56% and 54.03% for 2hrs and 24hrs respectively while the values obtained for coated bamboo was 0.59% and 2.53% for the same time duration.

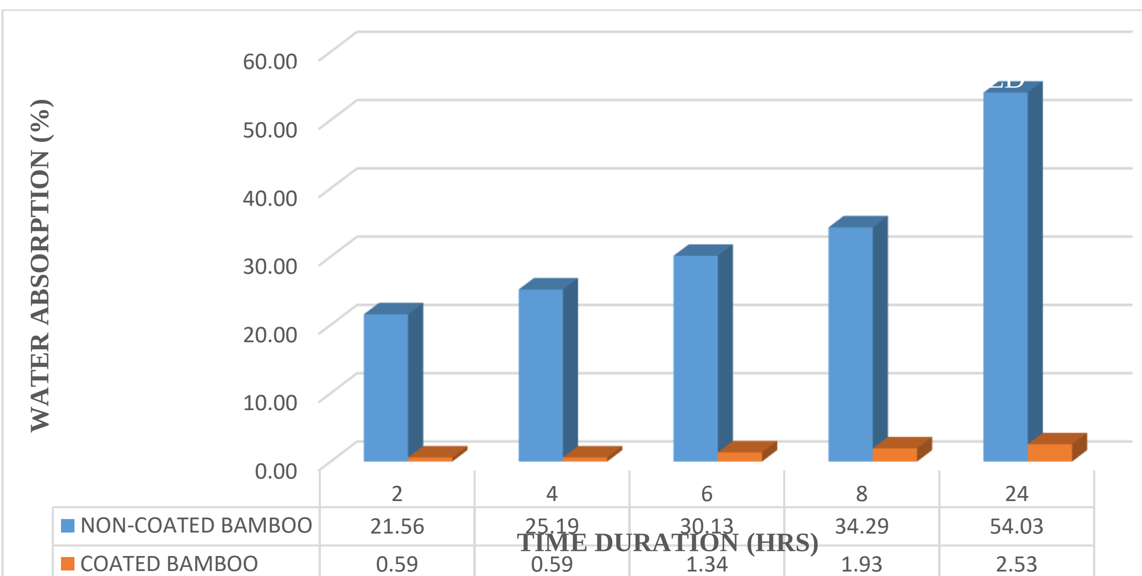


Figure 4.1: water absorption test on Bamboo

4.1.2 Tensile Strength Test Result

Table 4.1 show the result of tensile strength conducted on bamboo. The value obtained were 307.9 N/mm^2, 322.0 N/mm^2 and 393.3 N/mm^2 for 12mm, 14mm and 16mm respectively. This value makes bamboo a very viable alternative to steel. Mark (2011) have observed that the tensile strength of bamboo can reach up to 53ksi (365.4 N/mm^2). The values increases as diameter increases. The values obtained can compete well with mild steel reinforcement.

Table 4.1: Result of tensile strength test carried out on bamboo

DIAMETER OF BAMBOO (mm)	**MAXIMUM FORCE (N)**	**AREA (mm)**	**TENSILE STRENGTH (N/mm^2)**
12	6158	20	307.9
14	6439	20	322.0
16	7865	20	393.3

4.2 Results of Tests on Cassava Peel Ash (CPA)

Table 4.2 and Figure 4.2 shows the results of sieve analysis and other test done on CPA. The results from the values obtained shows that the CPA tested pass the ASTM C618 fineness criterion for fly ash and natural pozzolans, with less than 34 % of the material retained on the 45 microns sieve

Table 4.2: Results of test carried on cassava peel ash

S/N	**PARAMETERS**	**VALUES OBTAINED**
1	Fineness (% retained sieve 45microns)	30.50%
2	Specific Gravity	3.01
3	Bulk Density	866.67kg/m

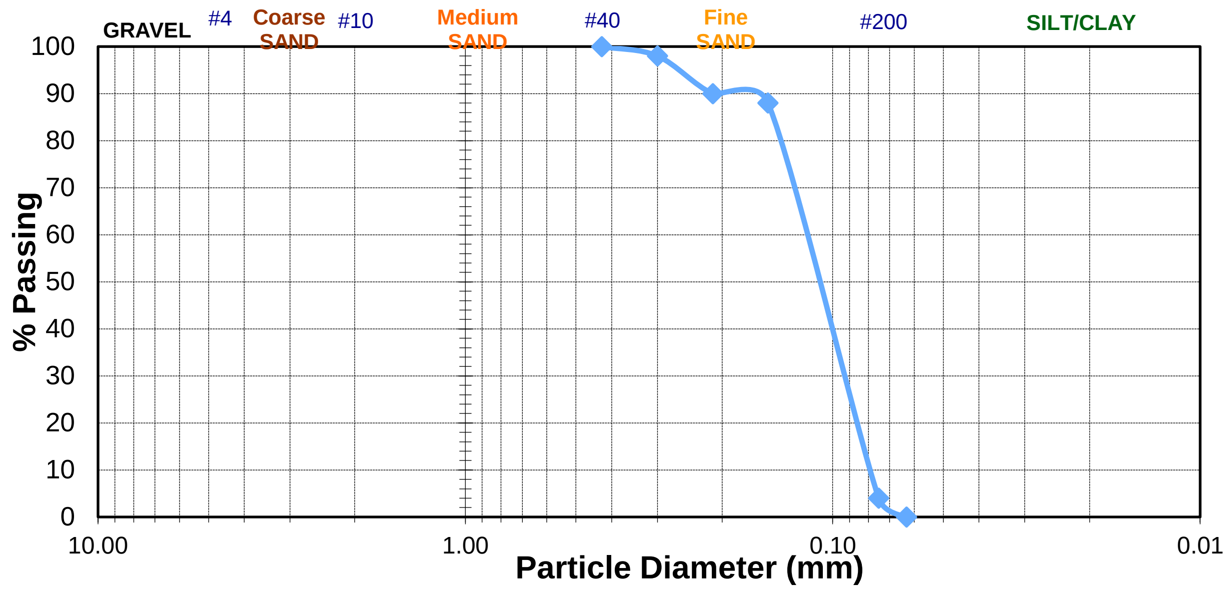


Figure 4.2: Sieve analysis graph for CPA

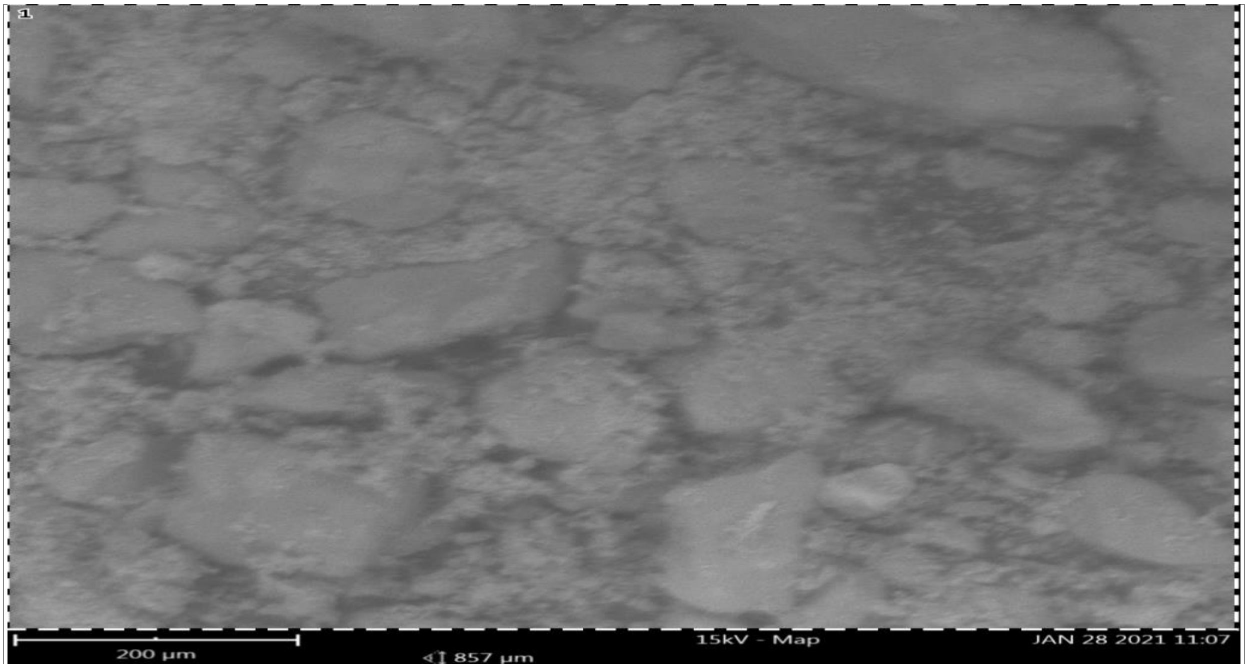
4.2.1 XRF and SEM analysis test on CPA

Table 4.3 shows the result obtained for CPA but the result for cement was as observed by Musbau *et al*, (2012). When the two results are compared, it can be shown that CaO and SiO2 are the primary oxides in cement and CPA, respectively. When cement is mixed with water, the most common source of binding and hardening properties is CaO, which is present in small amounts in CPA. When the dominating oxide SiO2 in CPA combines with Ca $(OH)_2$, a mechanism known as Pozzolanic reaction occurs, resulting in enhanced binding properties. Cement used will be reduced, which will reduce greenhouse gas emissions. If the percentage by weight of SiO_2, Fe_2O_3, and Al_2O_3 are added together, the summation of the three give a value higher than 70 % specified by ASTM C-618 (2005) and this further established that the CPA used is highly pozzolanic.

According to SEM images in Figure 4.3, the CPA sample has irregular or dispersed shaped and fibrous cavities (or pores), in addition, it may be said that these pores are either in closed or in open forms. The pore diameter of these cavities varied between 41 µm and 57 µm and these cavities generally did not intersect each other

Table 4.3: XRF analysis test on CPA and referenced XRF analysis test on Cement

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	SO_2	P_2O_5	Ag_2O	MgO	Y_2O_3	Nb_2O_5	Cl	TiO_2	Na_2O	V_2O_5
CPA	39.26	16.98	14.76	4.36	5.03	4.54	4.88	1.58	2.42	1.57	1.58	1.05	1.39	0.30	0.29



FOV: 857 µm, Mode: 15kV - Map, Detector: BSD

Figure 4.3: SEM Image on CPA

4.3 Results of Tests on Green Concrete

4.3.1 Compacting factor and Slump Test Result

Raheem *et al* (2015) report said that water-cement ratio increases as the percentage of CPA increases.it was stated that 0.6 w/c was achieved for normal concrete without CPA while 0.65 and 0.70 were achieved for those containing 5%, 10%, 15% and 20% CPA. This was due to high water absorption capacity of CPA and this implies that more water would be needed for the production of concrete containing CPA based on the amount used. In the work of Raheem *et al* (2015), the slump value increase as the CPA increases but in this research the reverse is the case i.e. the slump value reduces as CPA increase, this was so because the w/c was kept constant at 0.6 for all the concrete mix as presented in Table 4.4

Table 4.4: Compacting factor and Slump Test

SAMPLE ID	0% CPA	10% CPA	20% CPA
WEIGHT OF PARTIALLY COMPACTED CONCRETE (kg)	16.2	16.32	16.52
WEIGHT OF FULLY COMPACTED CONCRETE (kg)	16.5	17.0	18.1
COMPACTING FACTOR VALUE	0.98	0.96	0.91
TOTAL HEIGTH OF CONE (mm)	300	300	300
HEIGTH OF SLUMP (mm)	240	260	268
SLUMP VALUE (mm)	60	40	32

4.4 Results of Tests on Hardened Concrete

The result of the compressive strength is presented in Figure 4.4 and it shows that there is a decrease in compressive strength as CPA content increases, though a decrease trend was observed but the values obtained meet the requirement for grade 20 concrete. The water absorption result is presented in Figure 4.5 and it shows that increase in CPA leads to a decrease in water absorption rate and this is so because the ash repel water.

From figure 4.6 it can be noticed that the bulk density reduces as the percentage of CPA increases in the mix and all the values obtained still falls within the range of 2000 – 2400 kg/m^3 as specified by BS 811:1997 for normal concrete.

From Figure 4.7 the first flexural cracks were observed at an average of 0.25 of the ultimate load. As reported by previous researchers (Teo *et al*, 2006, Garson *et al*, 2010), it can be noticed that the control sample (0%) did not satisfy the 0.3mm requirement of BS8110 for maximum crack limit while for 10% and 20%, the values obtained satisfy the requirement of the code as it can be seen to be below 0.3mm. This outcome shows a positive contribution of the cassava peel ash.

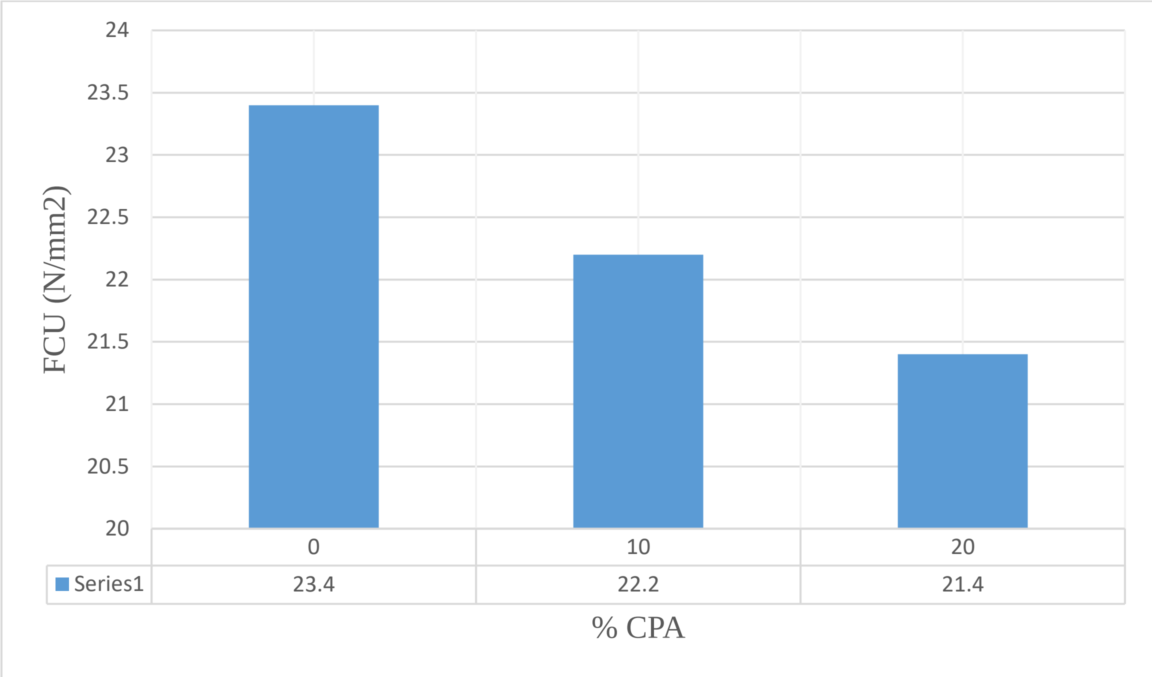


Figure 4.7: Compressive strength test result

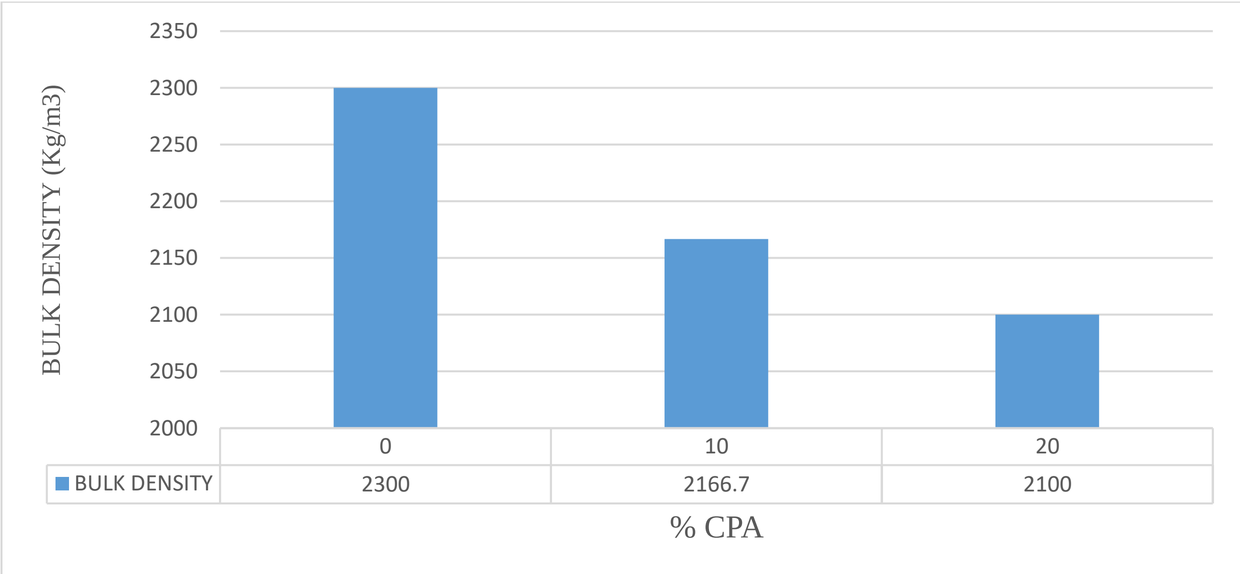


Figure 4.8: Bulk density

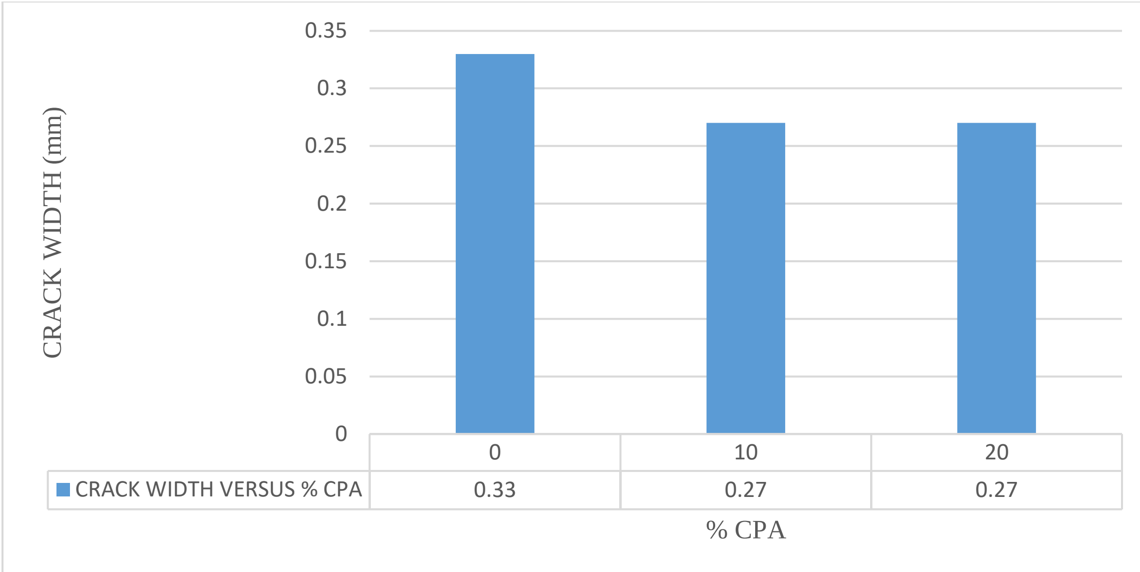


Figure 4.7: Measured Crack width of the beams

4.5 Result obtained using RSM for Flexural Strength and Flexural Strain

4.5.1 Normal Probability Plot

The result obtained for the normal probability plot is as presented in Figures 4.8a and 4.8b. According to Bradley (2007), a good estimated regression model is expected to explain the variation of the dependent variable in the sample and the normal probability plot is one of the tests used in evaluating the effectiveness of the model. The test requires that the error term (*ei*'s) should be normally and independently distributed with zero mean and variance (s^2). If the residuals plot is roughly along a straight line, normality is satisfied since the observations yi are normally and independently distributed. This error term is measured as the difference between the observed value (*y*i) and the corresponding fitted value ($\hat{y}_i$) expressed as, $e_i = y_i - \hat{y}_i$. Observations yi are also regularly and independently distributed as a result of this assumption.

The collected findings were analyzed for normality of residuals, as well as real versus expected plots for all properties considered. Figures 4.8a and 4.8b display the normal probability plots of both residuals for flexural strain and flexural strength of bamboo reinforced beams containing CPA. Figure 4.8a shows that all of the plotted points for flexural strain are very close to the distribution fitted line, while Figure 4.8b shows that all of the plotted points for flexural strength are also close to the distribution fitted line. In general, the normal distribution plot was found to be a preferable option for examining the attributes of interest.

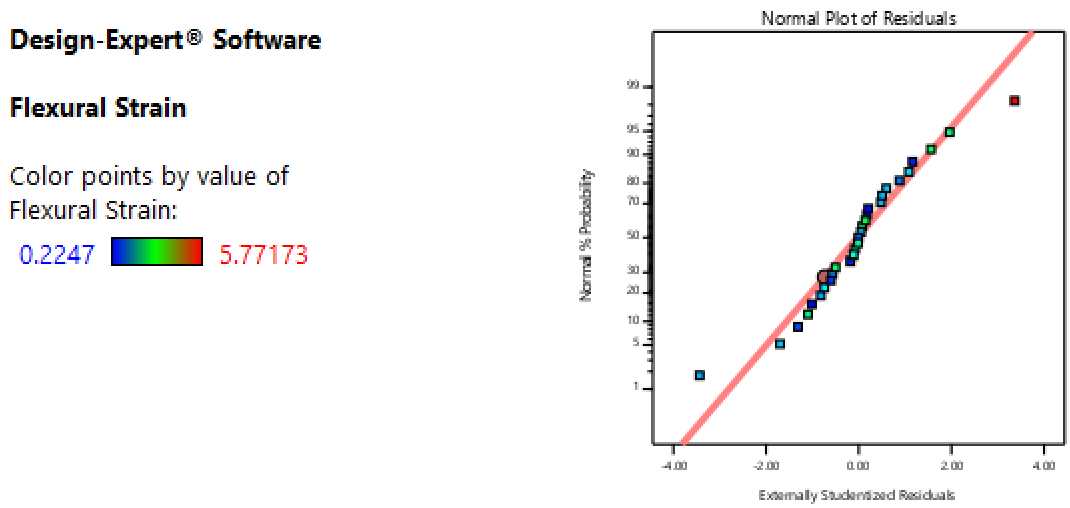


Figure 4.8a

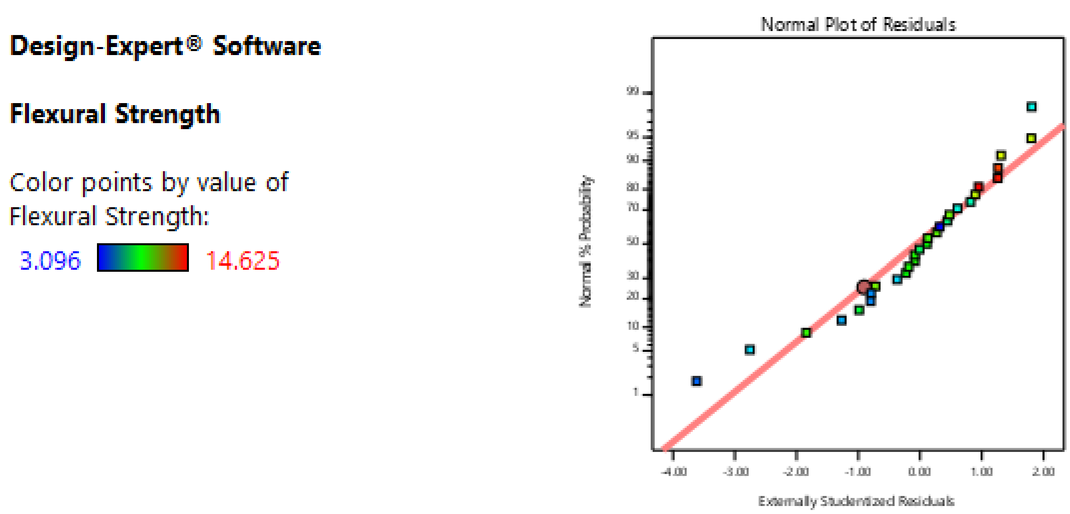


Figure 4.8b

4.5.2 Contour Plots for RSM at the Optimum Setting

Flexural Strength

To assess the interactive relationship between the mix design parameters and the investigated properties of a beam containing CPA and reinforced with bamboo respectively at optimized conditions, RSM has been used to generate a contour plot for all factors as shown in Figures 4.9(a-f) and Figures 4.10(a-f) as they relate to flexural strength and strain. The dependent responses' contour plots were pinched as a function of two independent factors, with the third independent variable held at mid-point. The contour plots of bamboo size shown in Figure 4.9a show that bamboo size affects flexural strength because the plot shows that flexural strength increases as bamboo size increases, i.e. 7 N/mm2 for bamboo size of 12 mm and 10 N/mm2 for bamboo size of 16 mm. The same trend was seen in the contour plots of beam length shown in Figures 4.9c and 4.9d. The value of flexural strength droped as the depth increases from 200 mm to 250 mm and this is in line with the work of Bazant and Novak (2001) where they concluded that the flexural tensile strength decreases with an increase of structural element size.

In all of the plot as shown in figure 4.9a-f, increase in bamboo size leads to a significant increase in flexural strength while on the other hand increase in CPA leads to decrease in flexural strength and this agree with the report of Raheem *et al.* (2015).

Flexural Strain

Flexural strain is defined by Yalcin (2020) as the nominal ratio fractional change in the length of an element of the test specimen's outer surface at mid-span when the largest strain occurs.

Figures 4.10a-f shows the contour plots for flexural strain. From Figures 4.10a, 4.10b and 4.10c, it was observed that the flexural strain increases as the length of beam and bamboo size increases and this agrees with the report of MohdAhmed *et al.* (2016) saying that the confining reinforcement increases ductility and large deflections in structures, providing a good warning of failure in the form of tensile cracks before complete failure of the flexural member.

For beam depth and CPA content, Figures 4.10d, 4.10e and 4.10f clearly show that the flexural strain values decrease as the depth and CPA content increase. This shows that increase in CPA content reduces the flexural strain which also reduces the crack width.

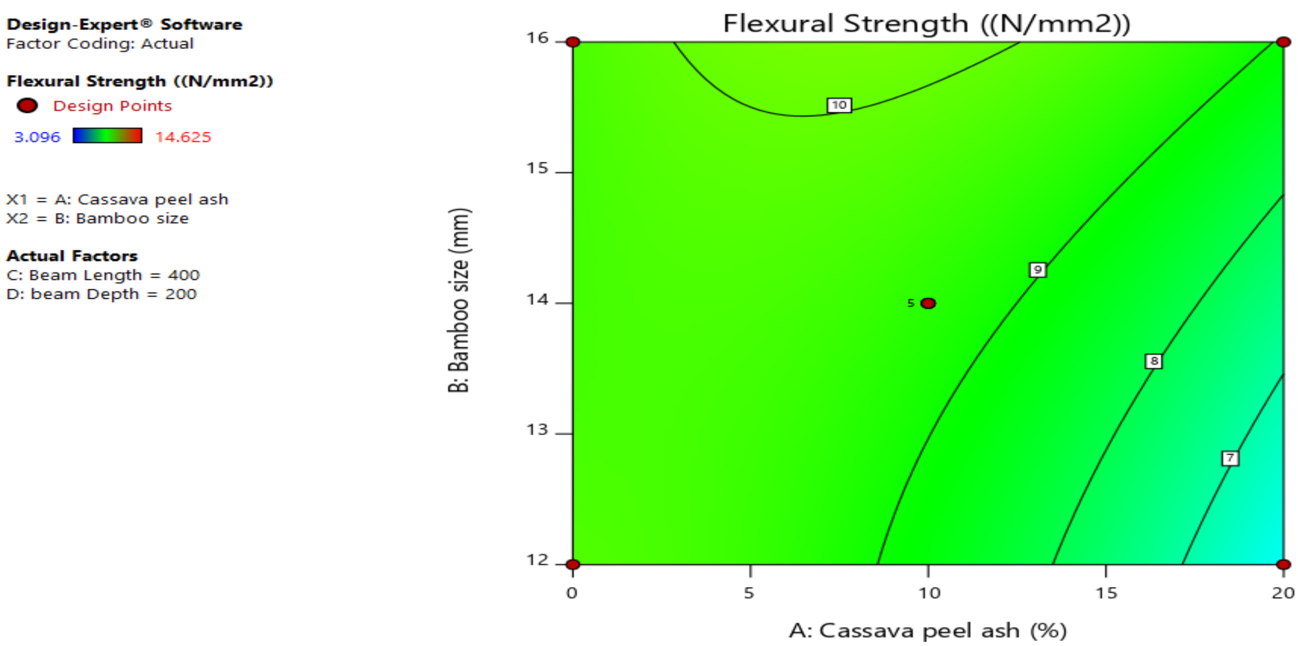


Figure 4.9a

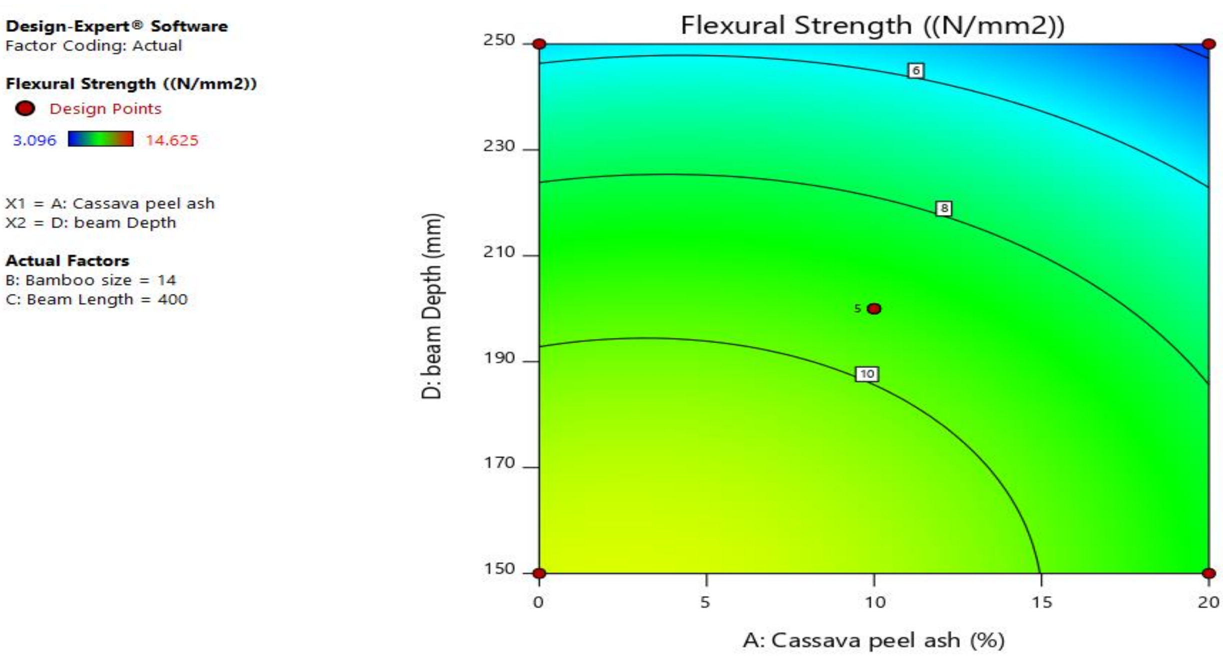


Figure 4.9b

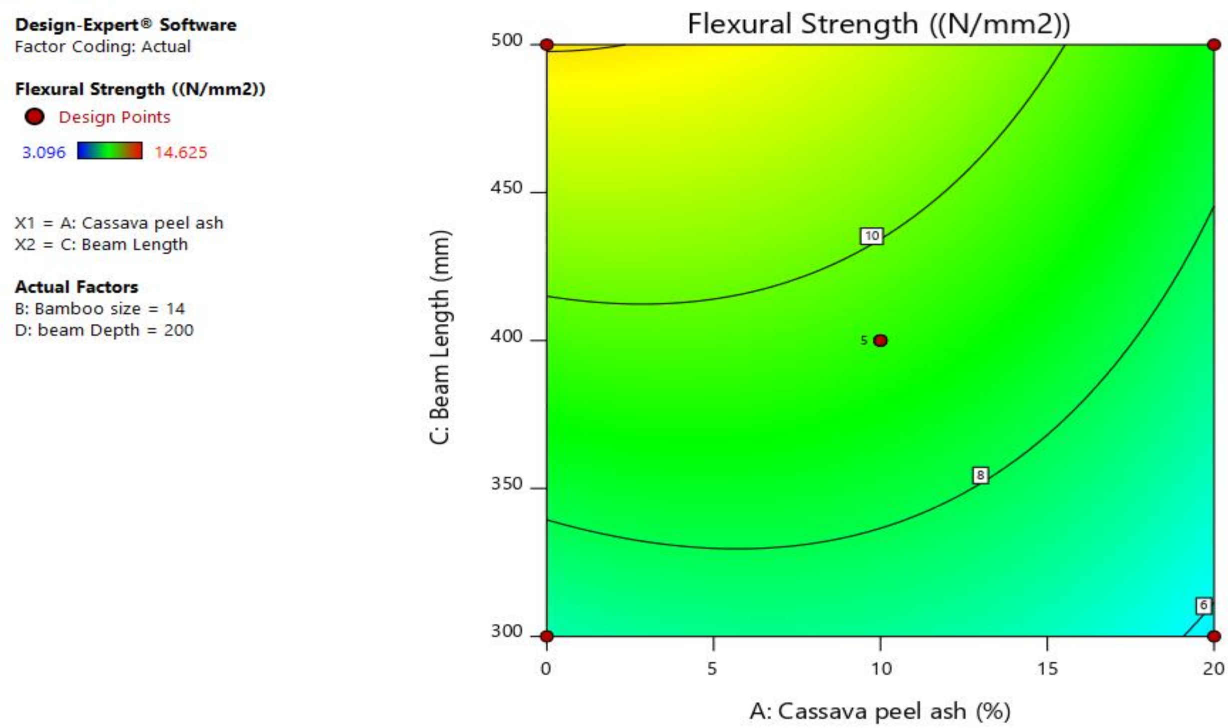


Figure 4.9c

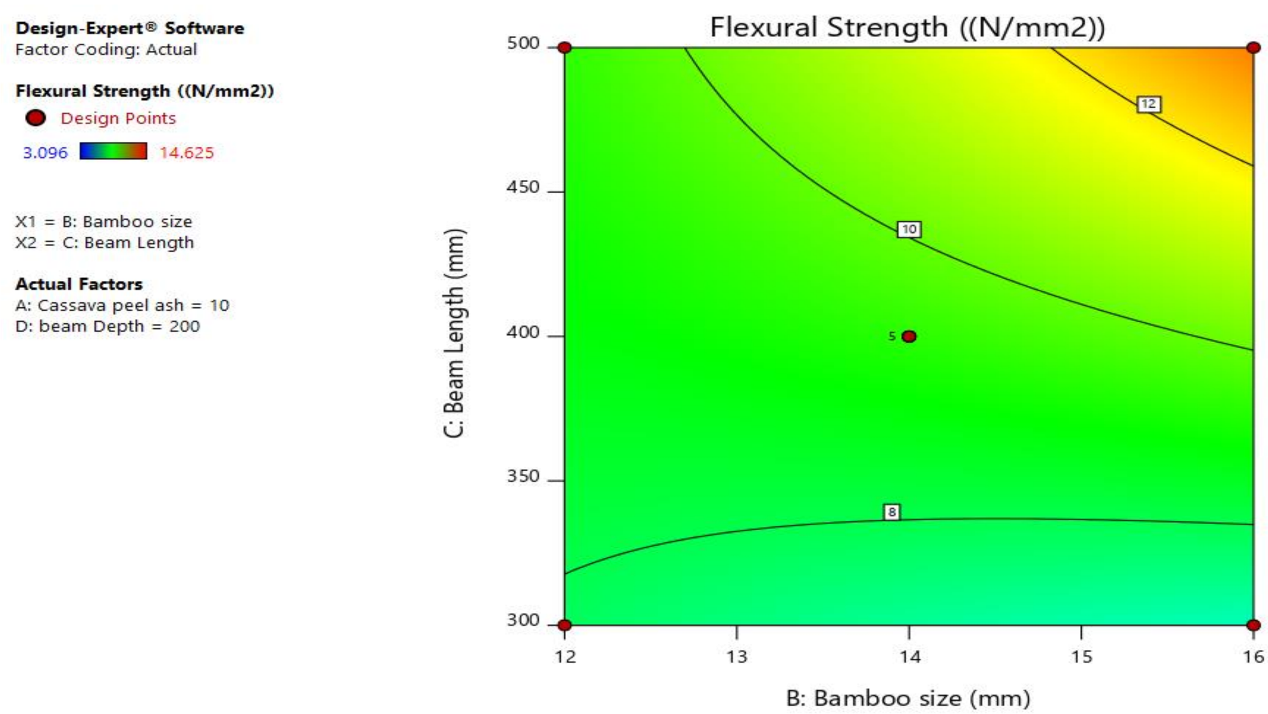


Figure 4.9d

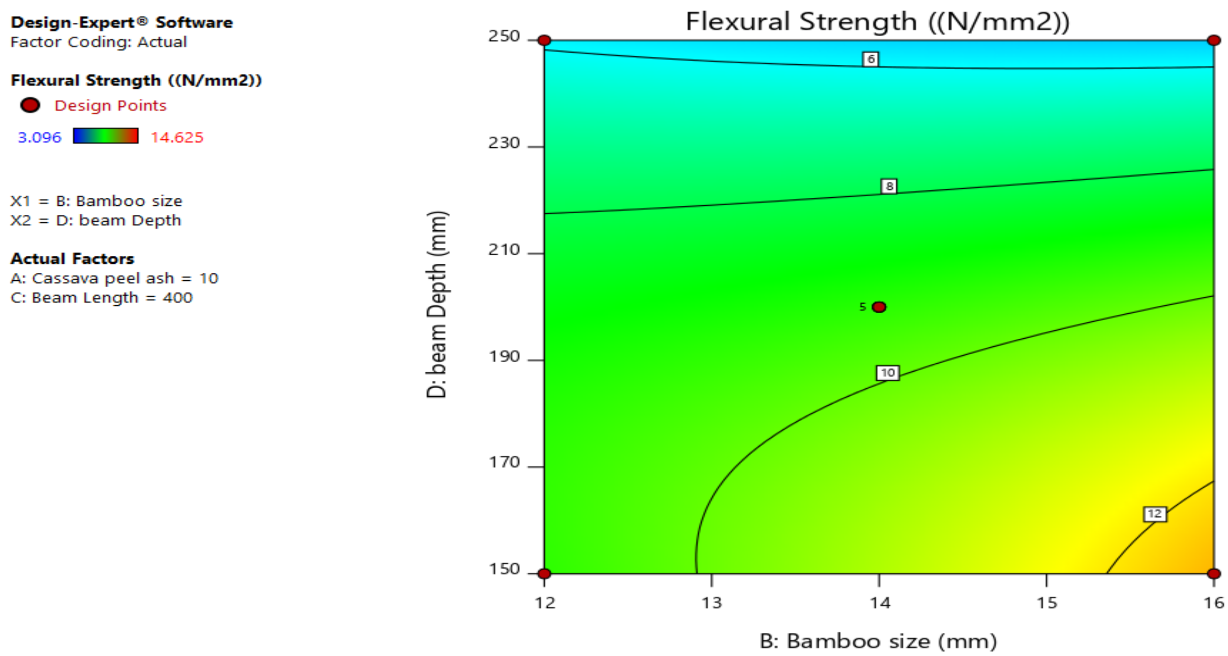


Figure 4.9e

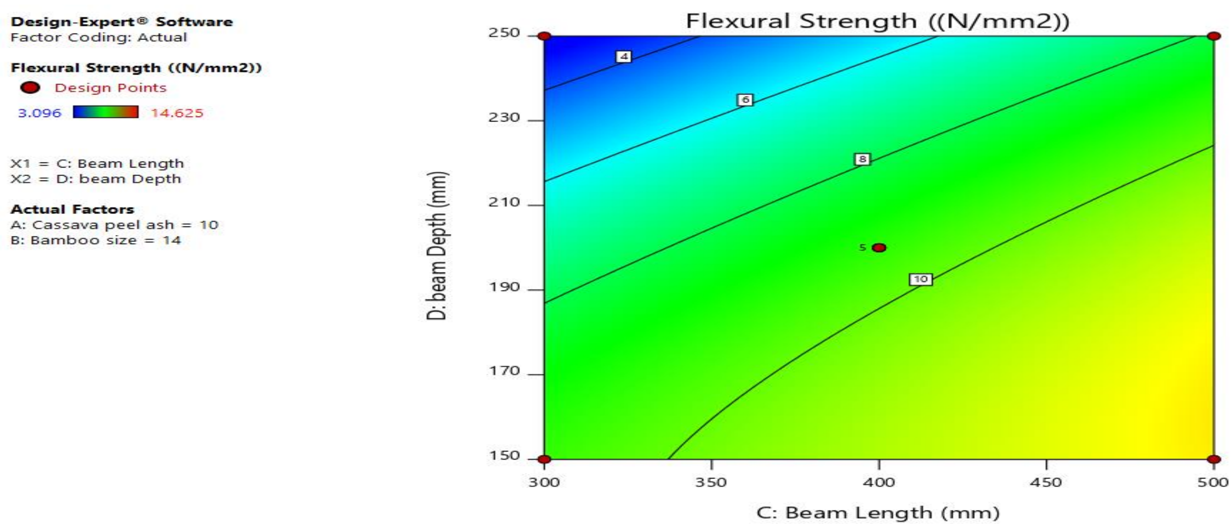


Figure 4.9f

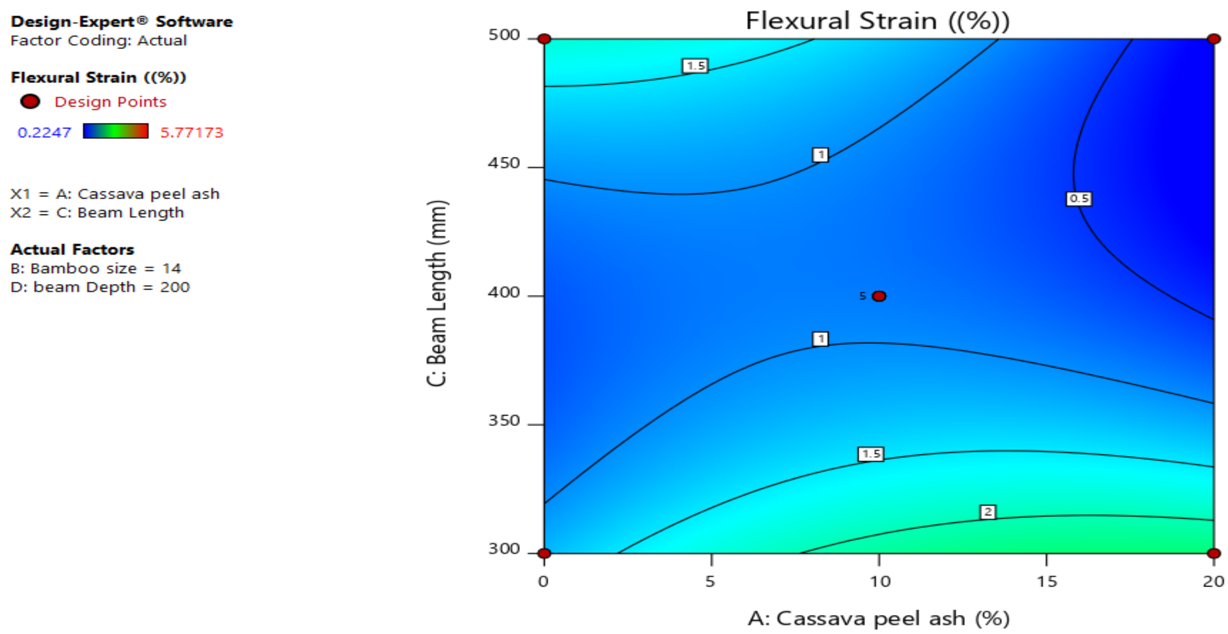


Figure 4.10a

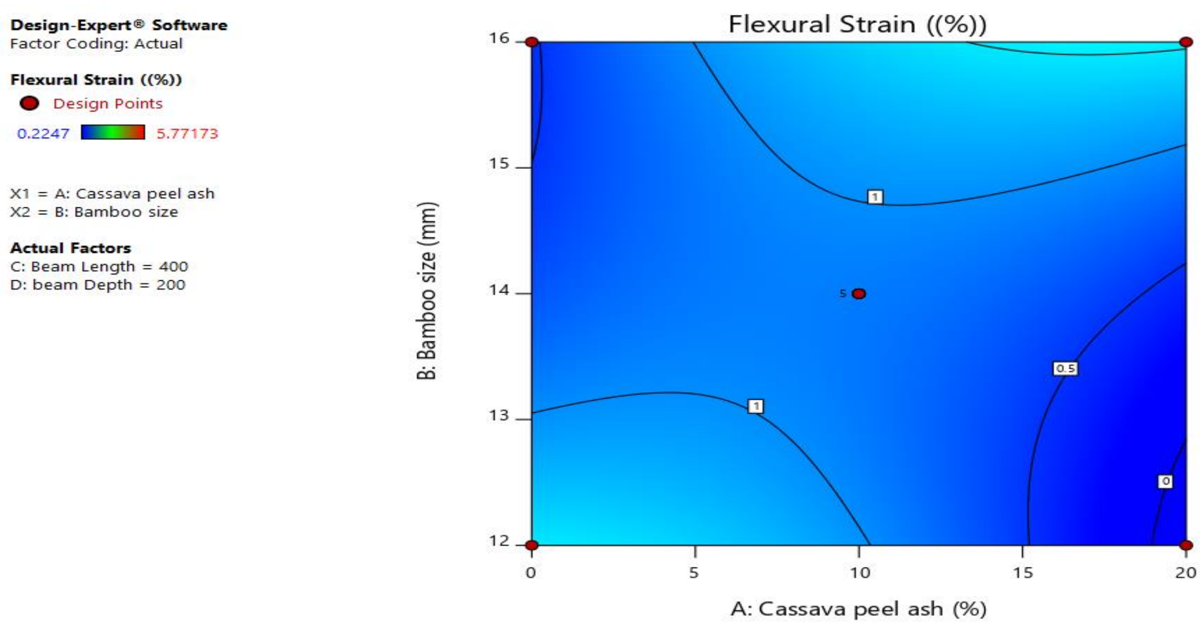


Figure 4. 10b

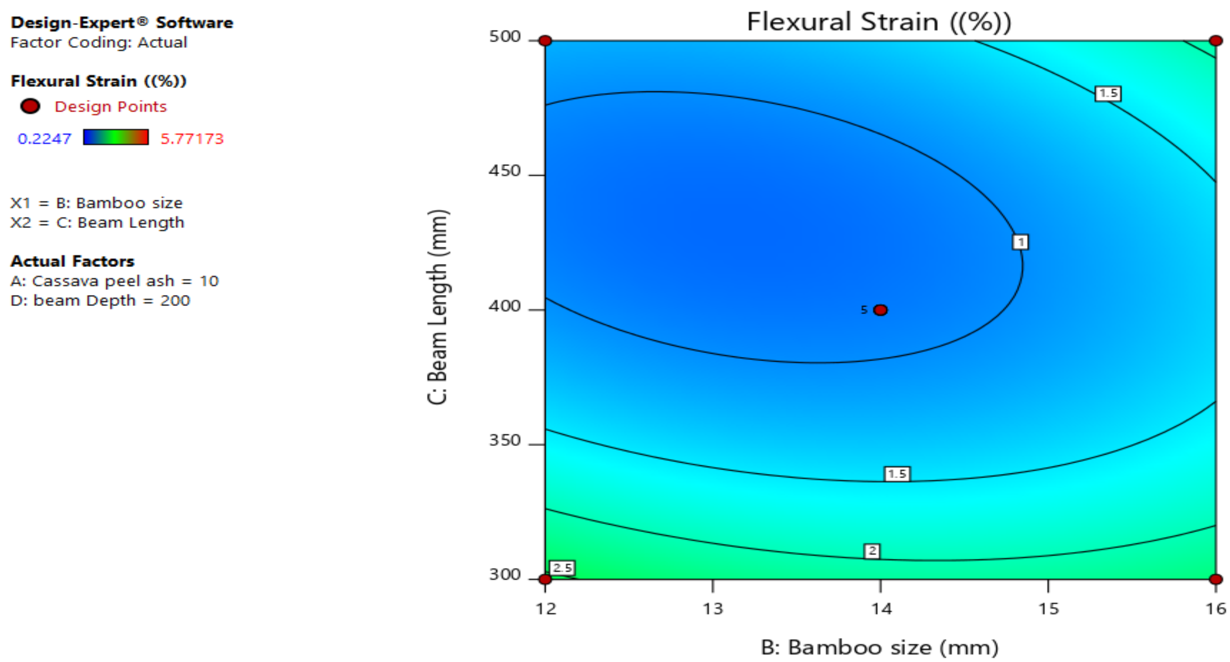


Figure 4.10c

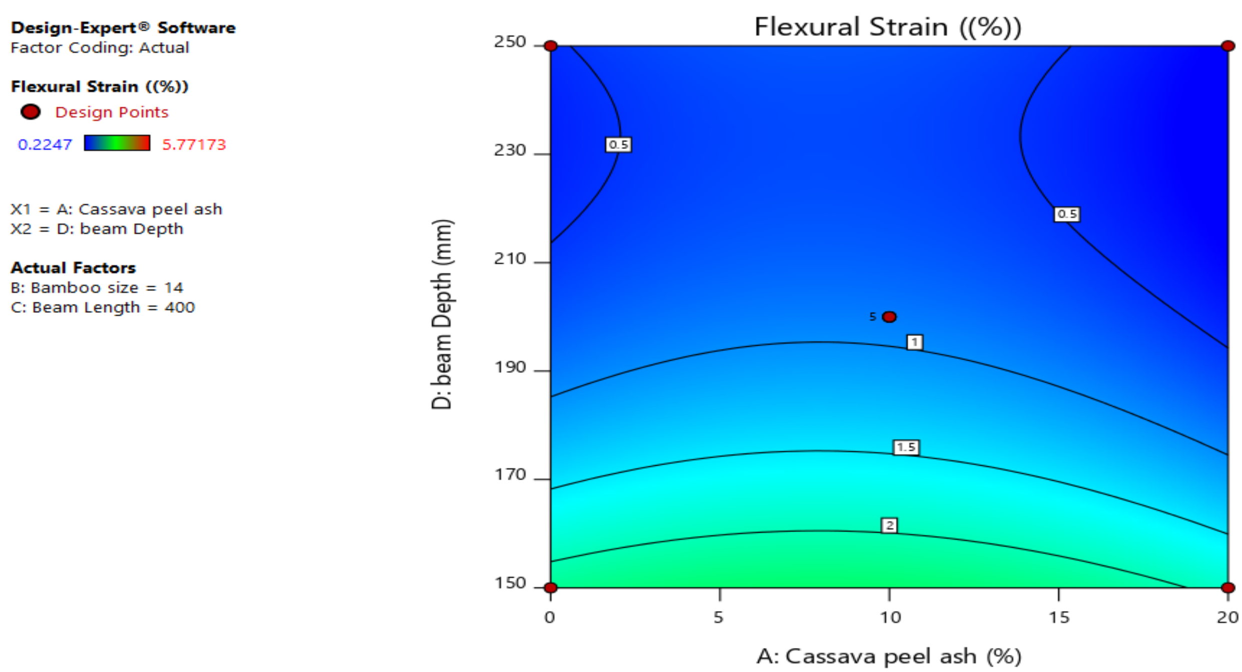


Figure 4.10d

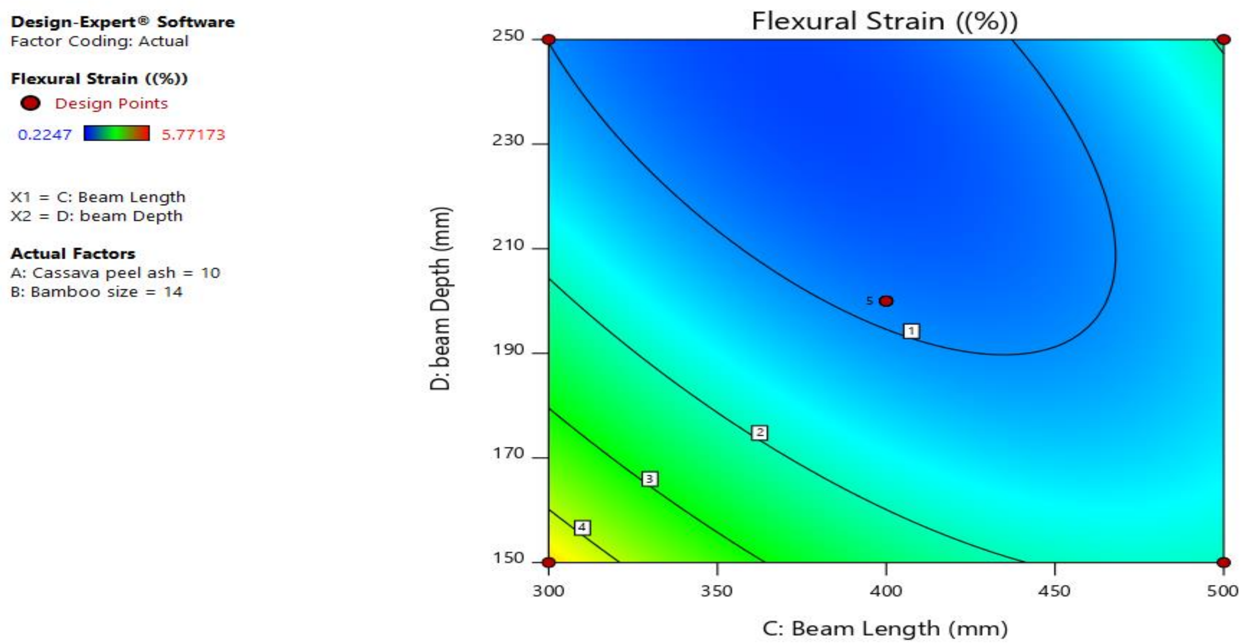


Figure 4.10e

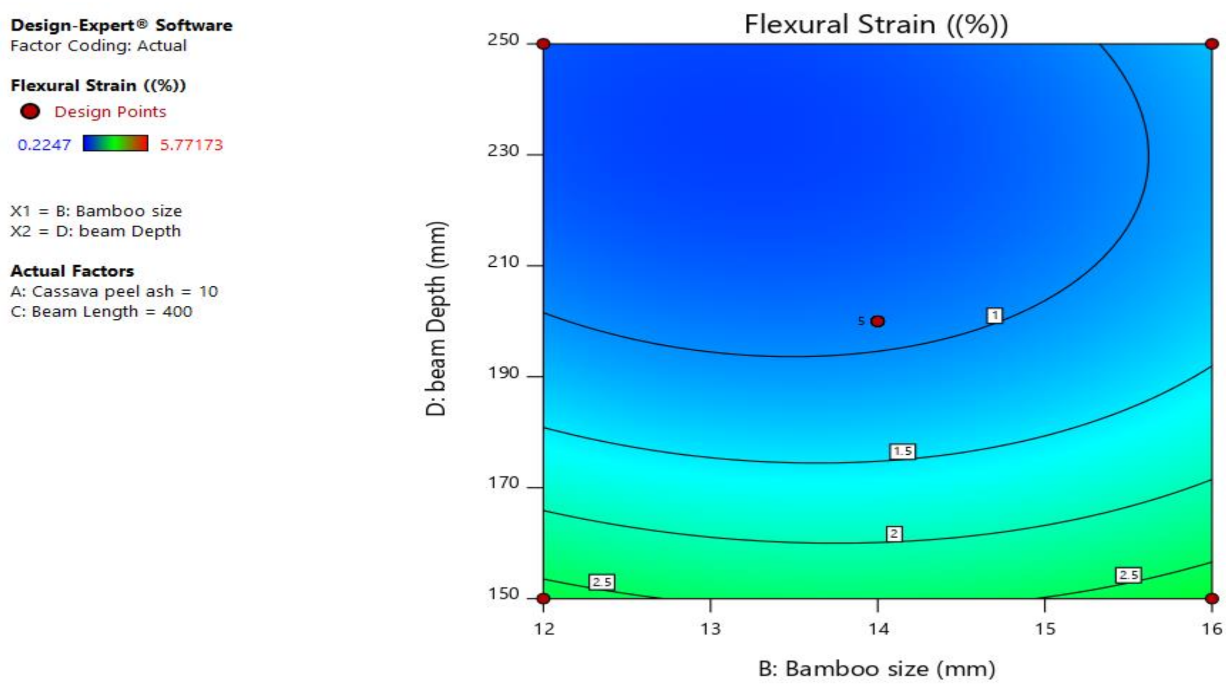


Figure 4.10f

4.5.3 The Analysis of Variance (ANOVA) and Regression Models Equations

To determine the contributions of the linear, interaction, and quadratic factors, an analysis of variance (ANOVA) was used. The student's t-test (p-value 0.05) was used to assess the statistically significant terms. Significant terms had p values less than 0.05, whereas inconsequential terms had p values more than 0.05.

The ANOVA for all investigated properties of a concrete beam containing CPA and reinforced with bamboo are presented in Tables 4.5 and 4.6. From Table 4.5 it was observed that the following linear terms were statistically insignificant. The expression A and B for flexural strength and expression A, B and C for flexural strain. However, linear expressions C and D were significant for flexural strength judging by the p-values obtained. For Table 4.6 only linear expression C was significant for flexural strain judging by the p-values obtained.

In Table 4.5 the interaction and quadratic effects were also evaluated using the same parameter. All the interaction and quadratic terms are insignificant for flexural strength while in Table 4.6 none of the interaction terms was significant for flexural strain while quadratic terms C^2 and D^2 are significant for flexural strain. In general, these quadratic terms signify the effect of the independent variables at a higher quantity.

By the application of multiple regression analysis on the data of the experiment, equations 4.1 (BRC containing CPA for flexural strength) and 4.2 (BRC containing CPA for flexural strain) were derived for all responses. According to Rostamiyan *et al*. (2015) the positive regression coefficient in equations 4.1 and 4.2 correspond to independent variables that have contributed positively to the response while those with negative coefficient have a negative contribution to the response.

Table 4.5: ANOVA Results for BRC containing CPA

Response	SoD	SoS	DoF	MS	F-value	P-value
Flexural Strength						
	Model	181.9391	14	12.99565	2.502544	0.048652
	A-Cassava peel ash	15.01549	1	15.01549	2.8915	0.111145
	B-Bamboo size	5.893775	1	5.893775	1.134951	0.304751
	C-Beam Length	48.27083	1	48.27083	9.295408	0.00867
	D-beam Depth	85.09646	1	85.09646	16.38684	0.001198
	AB	2.175625	1	2.175625	0.418955	0.52793
	AC	1.3225	1	1.3225	0.254671	0.621655
	AD	0.120178	1	0.120178	0.023142	0.881258
	BC	5.850352	1	5.850352	1.12659	0.306472
	BD	3.366002	1	3.366002	0.648184	0.434224
	CD	2.299604	1	2.299604	0.44283	0.516574
	A^2	4.494025	1	4.494025	0.865405	0.367995
	B^2	0.098563	1	0.098563	0.01898	0.892385
	C^2	0.133977	1	0.133977	0.0258	0.874685
	D^2	8.56992	1	8.56992	1.650291	0.219769
	Residual	72.70165	14	5.192975		
	Lack of Fit	72.00865	10	7.200865	41.56344	0.001329
	Pure Error	0.693	4	0.17325		
	Cor Total	254.6407	28			

SoD: Source of data; SoS: Sum of squares; DoF: Degree of freedom; MS: mean square SD: standard deviation; R2: Coefficient of determination; Adj. R^2: Adjusted coefficient of determination; AP: Adequate precision. A = Cassava Peel Ash, B = Bamboo Size, C = Beam Length and D = Beam Depth

Table 4.6: ANOVA Results for BRC containing CPA

Response	SoD	SoS	DoF	MS	F-value	P-value
Flexural Strain						
	Model	28.14925	14	2.010661	4.006391	0.006952
	A-Cassava peel ash	0.262408	1	0.262408	0.522868	0.481528
	B-Bamboo size	0.332698	1	0.332698	0.662926	0.429161
	C-Beam Length	1.93413	1	1.93413	3.853899	0.069813
	D-beam Depth	8.968867	1	8.968867	17.87113	0.000844
	AB	1.864044	1	1.864044	3.714246	0.074491
	AC	1.970795	1	1.970795	3.926955	0.067505
	AD	2.73E-05	1	2.73E-05	5.44E-05	0.994217
	BC	0.327642	1	0.327642	0.652851	0.432611
	BD	0.053923	1	0.053923	0.107446	0.747922
	CD	3.539295	1	3.539295	7.052308	0.018821
	A^2	0.834251	1	0.834251	1.662306	0.218187
	B^2	0.574639	1	0.574639	1.145011	0.302698
	C^2	4.705791	1	4.705791	9.376639	0.008444
	D^2	2.716399	1	2.716399	5.412627	0.035517
	Residual	7.026087	14	0.501863		
	Lack of Fit	6.109001	10	0.6109	2.664527	0.178781
	Pure Error	0.917086	4	0.229271		
	Cor Total	35.17534	28			

SoD: Source of data; SoS: Sum of squares; DoF: Degree of freedom; MS: mean square SD: standard deviation; R2: Coefficient of determination; Adj. R^2: Adjusted coefficient of determination; AP: Adequate precision. A = Cassava Peel Ash, B = Bamboo Size, C = Beam Length and D = Beam Depth

Prediction Equation

$$\text{Flexural Strength} = +9.33 - 1.12A + 0.70B + 2.01C - 2.66D + 0.74AB - 0.58AC + 0.17AD + 1.2BC - 0.92BD + 0.76CD - 0.83A^2 + 0.12B^2 - 0.14C^2 - 1.15D^2 \quad (4.1)$$

$$\text{Flexural Strain} = +0.90 - 0.15A + 0.17B - 0.40C - 0.86D + 0.68AB - 0.70AC + 0.003AD + 0.29BC + 0.12BD + 0.94CD - 0.36A^2 + 0.30B^2 + 0.85C^2 + 0.65D^2 \quad (4.2)$$

4.6 Optimization and Validation

The optimal values for the independent variables (A, B, C and D) were determined using the optimization tool of RSM. This was achieved by setting the desired goal for each mix design factors (A, B, C and D) chosen as presented in Table 4.7 for BRC containing CPA. The desirable flexural strength and flexural strain were defined as being maximum in order to attain the highest strength. Results from the optimization gave several solutions, however, the solution with the highest desirability was selected and the details are as presented in Table 4.7.

The process involved interpolating factors within the range considered in the mix design to obtain a response for all properties investigated. For validating the model prediction, a laboratory experiment was conducted using the optimum mix design proportion. From the results obtained, it was observed that the experimental results were close to those predicted by the models. The absolute relative per cent errors (PE) for BRC containing CPA were 0.842 and 1.161 for flexural strength (R1) and flexural strain (R2) respectively. From the relatively low values obtained for PE, it could be inferred that the model predicted the desired responses with good accuracy.

In general, optimization considers all responses simultaneously and in the case of BRC containing CPA, higher bamboo size obtained from lower CPA, medium beam length and depth was recommended.

Table 4.7: Optimum conditions achieved for BRC containing CPA

	Parameters	Unit	Goal	Model prediction	Laboratory experiment	SD	PE
CPA	A	%	In range	0	0		
	B	%	In range	16	16		
	C	%	In range	470	470		
	D	%	In range	173	173		
	R1	N/mm^2	Maximum	13.690	12.856	±0.42	6.486
	R2	%	Minimum	1.536	1.540	±0.007	0.260

Other details on all the results are attached as appendix B.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In general, it can be deduced from the results obtained from a test conducted on hardened concrete that CPA causes a downward trend on the compressive strength which is a negative contribution but reduces the water absorption, bulk density and flexural crack width which can be seen as a positive contribution on the other hand.

The result obtained from optimization, prediction and validation using the RSM tool shows that bamboo size and beam length are a major contributor to the increase in flexural strength of beam and this shows that it can be used as an alternative to steel in structures of low magnitude of load.

5.2 Conclusions

The following conclusions were drawn from this study:

i. The result of chemical test carried out on CPA shows that is a good pozzolanic material and the tensile strength of the bamboo used which ranges from 307.9 for 12 mm size to 393.3 N/mm^2 for 16mm also show that bamboo is a viable alternative to steel and for its sustainable and eco-friendly nature also.

ii. At constant w/c of 0.6, the slump value of fresh concrete reduces from 60 to 32 mm as percentage of CPA increases and this is so because of its ability to absorb water.

iii. The water absorption of hardened concrete decreases with a corresponding increase in the percentage of CPA and the bulk density also decreases as the CPA increases because it is lighter than cement.

iv. Compressive strength and flexural strength of concrete decrease as the percentage of CPA increases which is in line with previous researches. The compressive values obtained are 23.4 N/mm^2, 22.2 N/mm^2 and 21.4 N/mm^2 for 0 %, 10 % and 20 % respectively which shows that CPA addition up to 20% still meets the minimum requirement for grade 20 concrete.

v. Increase in bamboo size and length of beam leads to increase in flexural strength i.e. from 6 N/mm^2 to 12 N/mm^2 and bamboo sizes of 12 mm, 14 mm and 16 mm and length of 400 mm, 500 mm and 600 mm.

vi. Increase in CPA leads to a reduction in flexural strain e.g. as CPA increases from 5 % to 20 %, flexural strain reduces from 2 to 0.

vii. Increase in CPA also leads to reduction in flexural crack width which comply with BS8110 specification of 0.3 mm.

viii. The significant of the model parameters and the result obtained established the effectiveness of RSM as optimization tool.

ix. From the results obtained at optimal condition using RSM tool, it shows that CPA has a negative contribution as it can be seen that the optimum recommendation for CPA was 0 %. This also further established that flexural strength increases as bamboo size increases.

x. For validating the model prediction, a laboratory experiment was conducted using the optimum mix design proportion. From the results obtained, it was observed that the experimental results were close to those predicted by the models. The absolute relative per cent errors (PE) for BRC containing CPA were 0.842 and 1.161 for flexural strength (R1) and flexural strain (R2) respectively. From the relatively low values obtained for PE, it could be inferred that the model predicted the desired responses with good accuracy.

5.2 Recommendations for Future Research

The following recommendations are considered as logical extensions of this work:

i. Cylindrical samples can also be tested to further investigate the effect of shape and sizes on the performance of BRC containing CPA.

ii. Superplasticizer and strength enhancing chemicals can be used in order to study the performance of CPA beyond 20%.

iii. Based on the result obtained and the aggregates batching adopted in this study, CPA up to 20% is recommended for use in concrete work.

iv. That BRC containing CPA should further be subjected to more reliability check using other approaches to further validate its viability.

v. Fire resistance of concrete containing bamboo as reinforcement should be tested.

CONTRIBUTION TO KNOWLEDGE

The contribution of this research to knowledge is as follows:

i. The use of RSM tool helped to understand the optimal condition which can give a better flexural strength of beam.
ii. The RSM analysis also revealed that increase in bamboo size and beam length leads to a corresponding increase in flexural strength while the depth of beam leads to decrease in flexural strength.
iii. The compressive strength obtained in this study was found to be higher than what was obtained in previous works and this can be attributed to the batching method used in this research which contained two type of fine aggregate.
iv. The CPA also reduces the bulk density and flexural crack width of the concrete cubes and beam tested.

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APPENDIX A

Figure 1: Mixing the CPA and cement together

Figure 2: Already mixed concrete poured into moulds

A C

C

Figure 3: Demoulded concrete beams and cubes before curing

Figure 4: Bamboo as Reinforcement Material for Column

Figure 5: A Whole Built with BRC

Figure 6: BR used for Column Starter Bar

Sample ID	SAND
Mass Of Bottle + sample +Water (M3)	77
Mass Of Bottle + sample (M2)	32
Mass Of Bottle Full Of Water Only (M4)	67
Mass Of Bottle (M1)	16
Mass Of Water Used (M3-M2)	45
Mass Of sample Used (M2-M1)	16
Volume Of sample (M4-M1)-(M3-M2)	6
Gs=(M2-M1)/(M4-M1)-(M3-M2)	2.67

APPENDIX B

Table 1: Result of specific gravity of sand

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
	4.750	530.0	530.0	0.00	0	100
	2.000	520.0	680.0	160.00	32.0	68.0
	1.180	491.0	564.0	73.00	14.6	53.4
	0.600	475.5	568.0	92.50	18.5	34.9
	0.425	437.5	501.0	63.50	12.7	22.2
	0.300	437.0	505.0	68.00	13.6	8.6
	0.150	400.0	404.0	4.00	0.8	7.8
	0.075	371.0	405.5	34.50	6.9	0.9
	0.063	381.5	382.0	0.50	0.1	0.8
Pan		387.5	391.5	4.00	0.8	0.0

	TOTAL:	500.00	100.0

Table 2: Sieve Analysis

From the Particle Size Distribution (PSD) curve in Figure (4.1.2);

Effective size = D_{10} = 0.15 mm

The Uniformity Coefficient $C_u = \frac{D60}{D10}$

D_{60} = 0.6

Therefore, $C_u = \frac{0.6}{0.15}$ = 4.00

The Fineness modulus of the sand = $\frac{301.84}{100}$ = 3.02 < 3.20 (Suitable for concrete works)

Therefore means that the sand is well graded

Table 3: Natural Moisture Content of Sand

SAMPLES ID	WEIGHT OF EMPTY CAN (g) A	WEIGHT OF WET SAMPLE (g) B	WEIGHT OF OVEN-DRIED SAMPLE (g) C	MC (%) = (B-C/C-A)*100
A	13.5	42	40.5	5.56
B	13.5	43.5	41.5	7.14
C	13.5	96.5	93.5	3.75
			AVERAGE	5.48

Silt/Clay Content Test Result on Sand

$$\% \text{ Silt/Clay Content} = \frac{\text{Height of silt}}{\text{Total height of sample}} \times 100$$

Height of silt = 4 mm

Total height of sample = 56 mm

$$\text{Silt/Clay Content} = \frac{4}{56} \times 100 = 7.1\ \%$$

Therefore, the Silt/Clay content of the fine aggregate is 7.1 %

Table 4

A	0.105	0.546	0.00025	1764.00
B	0.105	0.553	0.00025	1792.00
C	0.105	0.52	0.00025	1692.00
AVERAGE				1749.33

The bulk density of the sand used is 1749.33 kg/m^3 and is within the specified range.

Consistency Test Result on Cement

Mass of cement = 400g

Mass of water = 240g

$$\text{Water content } (\%) = \frac{\text{mass of water (g)}}{\text{mass of cement (g)}} \times 100$$

$$\text{Water content } (\%) = \frac{240}{400} \times 100 = 0.6$$

Therefore the water cement ratio is 0.6

Soundness Test Result on Cement

Diameter of sample before test =30.00 mm

Diameter of sample after test = 28.55 mm

Difference of in diameter = 30.00 – 28.55 = 1.45 mm

Soundness (%) = $\frac{\text{Difference in diameter}}{\text{Diameter of sample before test}} \times 100$

Soundness (%) = $\frac{1.45}{30.00} \times 100 = 4.8$

Soundness (%) = 4.8

Fineness Test (By Sieve Analysis) Result on Cement

Weight of sample before test = 100.0 g

Weight of sample after test = 16.0 g

Fineness value (%) = $\frac{\text{Weight of sample after test}}{\text{Weight of sample before test}} \times 100$

Fineness value (%) = $\frac{16}{100} \times 100 = 16$

Fineness value (%) = 16

Table 5: Initial and Final Setting Time of Cement

TIME(min)	PENETRATION(mm)	REMARK
0	40	
5	**5**	← **Initial Setting Time**
10	40	
15	40	
20	40	

25	40	
30	40	
35	40	
40	38	
45	**34**	
50	L.P	
55	L.P	
60	L.P	
120	L.P	
180	L.P	
240	L.P	
300	L.P	
360	L.P	
420	L.P	
480	L.P	
540	L.P	← **Final Setting Time**
600	L.P	Mixing Time = 5min Final Setting Time = 630+5= 635mins
630	**N.P**	Initial Setting Time = 5+5 = 10mins

Note: LP: Low penetration

NP: No penetration

Table 6: Fineness test on CPA

Sample ID	A	B	C
Total mass of sample (g)	100	100	100
Mass passing through 45 micron sieve (g)	32.0	29.5	30.0

% Fine passing through 45 micron sieve (%)	32.0	29.5	30.0
AVERAGE		30.50	

Table 7: Specific gravity test on CPA

Sample ID	**A**	**B**	**C**
Mass Of Bottle + sample +Water (M3)	75	73	72
Mass Of Bottle + sample (M2)	28.1	25	23.4
Mass Of Bottle Full Of Water Only (M4)	67	67	67
Mass Of Bottle (M1)	16	16	16
Mass Of Water Used (M3-M2)	46.9	48	48.6
Mass Of sample Used (M2-M1)	12.1	9	7.4
Volume Of sample (M4-M1)-(M3-M2)	4.1	3	2.4
Gs=(M2-M1)/(M4-M1)-(M3-M2)	2.95	3.00	3.08
AVERAGE GS			**3.01**

Table 8: Sieve analysis test on CPA

Sieve Number	Diameter (mm)	Soil Passing (%)
	0.43	100
	0.30	98
	0.21	90
	0.15	88
	0.08	4

	0.06	0
Pan		0

Table 9: Bulk density test on CPA

SAMPLES ID	WEIGHT OF EMPTY BEAKER (kg)	WEIGHT OF BEAKER+SAMPLE (kg)	VOLUME OF BEAKER/MOULD (m3)	BULK DENSITY(kg/m3)
A	0.1045	0.3205	0.00025	864.00
B	0.1045	0.298	0.00025	774.00
C	0.1045	0.345	0.00025	962.00
			AVERAGE	866.67

Table 10: Water absorption test on bamboo

Table 11: Measured Crack Width

SAMPLES ID	2HRS	4HRS	6HRS	8HRS	24HRS
NON-COATED BAMBOO					
AVERAGE WEIGHT OF WET SAMPLE (A) g	46.8	48.2	50.1	51.7	59.30
AVERAGE WEIGHT OF DRIED SAMPLE (B) g	38.5	38.5	38.5	38.5	38.5
WATER ABSORPTION % =A-B/B*100	21.56	25.19	30.13	34.29	54.03
COATED BAMBOO					
AVERAGE WEIGHT OF WET SAMPLE (A) g	67.7	67.7	68.2	68.6	69.00
AVERAGE WEIGHT OF DRIED SAMPLE (B) g	67.3	67.3	67.3	67.3	67.3
WATER ABSORPTION % =A-B/B*100	0.59	0.59	1.34	1.93	2.53

S/N	% CPA	CRACK WIDTH (mm)
1	0	0.33

2	10	0.27
3	20	0.27

Table 12: Fineness Test on Cement

Sample ID	A	B	C
Total mass of sample (g)	100	100	100
Mass of sample retained on 45 micron sieve (g)	28.5	26.0	25.5
% Fine retained on 45 micron sieve (%)	28.5	26.0	25.5
AVERAGE		26.67	

Table 13: Fineness Test on CPA

Sample ID	A	B	C
Total mass of sample (g)	100	100	100
Mass of sample retained on 45 micron sieve (g)	32.0	29.5	30.0
% Fine retained on 45 micron sieve (%)	32.0	29.5	30.0
AVERAGE		30.50	

Table 14: Flakiness and Elongation Test on Coarse Aggregate

Sample ID	A	B
TOTAL WEIGHT OF SAMPLE (g)	1550	1550
TOTAL WEIGHT OF SAMPLE PASSING THROUGH THICKNESS GUAGE (g)	403.5	409.0
FLAKINESS INDEX (%)	**26.0**	**26.4**

AVERAGE		26.2
TOTAL WEIGHT OF SAMPLE RETAINED ON VARIOUS LENGTH GUAGE (g)	419.0	414.0
ELONGATION INDEX (%)	27.0	26.7
AVERAGE	26.87	

Table 15: Tensile Strength Test on Bamboo

DIAMETER OF BAMBOO (mm)	MAXIMUM FORCE (N)	AREA (mm2)	TENSILE STRENGTH (N/mm^2)
12	6158	20	307.9
14	6439	20	322
16	7865	20	393.3

Table 16: Water Absorption Test on Granite

SAMPLES ID	WEIGHT OF SATURATED SURFACE DRIED SAMPLE (A) g	WEIGHT OF OVEN-DRIED SAMPLE (B) g	WATER ABSORPTION % =A-B/B*100
A	182	158.5	14.83

B	184	159	15.72
C	180.5	162	11.42
AVERAGE			**13.99**

Table 17: Abrasion Test on Granite

Sample ID	A	B	C
Mass ofsample (g)	3000	3000	3000
Mass of washed&oven dried sample retained on 2mm sieve (g)	1986.0	1982.0	1988.0
AAV(%)	33.8	33.9	33.7
AVERAGE		**33.82**	

Table 18&Figure 1: Raw data for Tensile Test on Bamboo

Ref 1 :
Ref 2 :
Ref 3 :

Test Name : Basic Tensile
Test Type : Tensile
Test Date : 31/05/2021 11:15
Test Speed : 20.000 mm/min
Pretension : Off
Sample Length : 400.000 mm

Comments :

Test No	Force @ Peak (N)	Elong. @ Break (mm)
1	10565.000	35.852

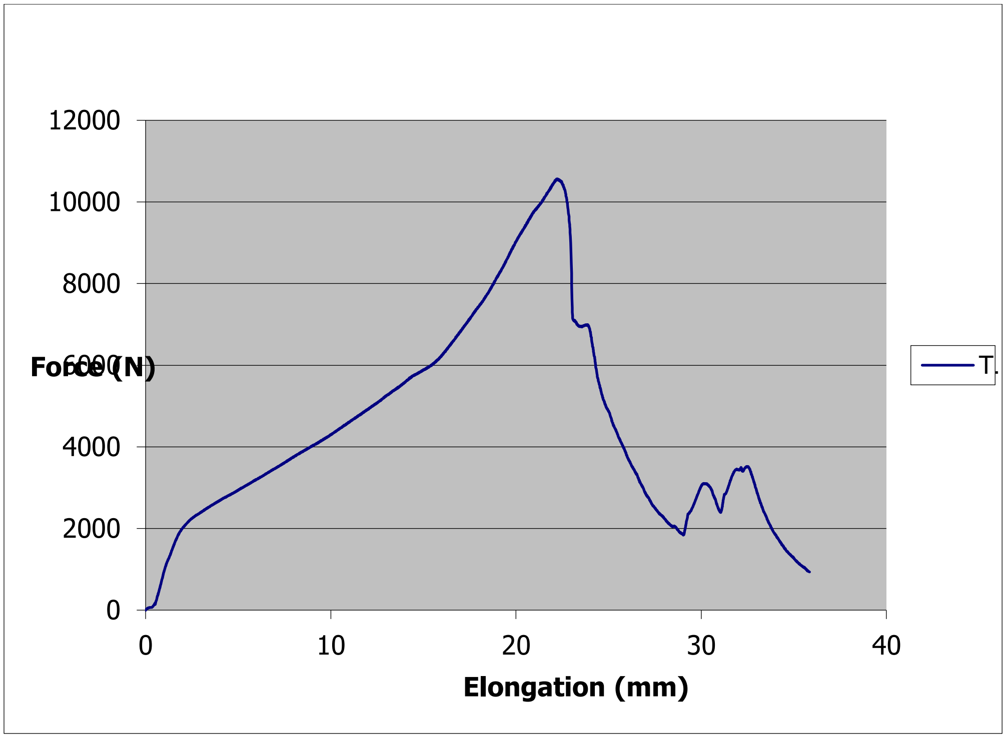

Table 19: Crushing Test on Granite

Sample ID	A	B	C
Mass of empty mould (g)	6500	6500	6500
Mass of mould+sample (g)	7089	7089	7089
Mass of sample passing through 2.36mm sieve (g)	55.0	57.0	56.0
AIV(%)	9.3	9.7	9.5
AVERAGE		**9.51**	

Table 20: Impact Test on Granite

Sample ID	GRANITE	TREATED PKS	UNTREATED PKS
Mass of empty mould (g)	2994.5	2994.5	2994.5
Mass of mould+sample (g)	3562	3565	3568
Mass of sample passing through 2.36mm sieve (g)	57.0	59.5	56.5
AIV(%)	10.0	10.4	9.9
AVERAGE		**10.11**	

Table 21: Combine Sieve Analysis for Fine and Coarse Aggregates

Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Sand (g)	Sand Retained (g)	Sand Retained (%)	Sand Passing (%)	Mass of Sieve & Granite (g)	Granite Retained (g)	Granite Retained (%)	Granite Passing (%)
25.000	542.0	542.0	0.00	0	100	542.0	0.0	0	100
19.500	538.0	538.0	0.00	0	100	688.0	150.0	15	85
13.500	533.0	533.0	0.00	0	100	770.0	237.0	23.7	61.3
10.000	530.5	530.5	0.00	0	100	864.0	333.5	33.35	27.95
4.750	530.0	530.0	0.00	0	100	802.0	272.0	27.2	0.75
2.000	520.0	675.5	155.50	31.1	68.9	527.5	7.50	0.75	0
1.180	491.0	564.0	73.00	14.6	54.3	491.0	0.00	0	0
0.600	475.5	568.0	92.50	18.5	35.8	475.5	0.00	0	0
0.425	437.5	501.0	63.50	12.7	23.1	437.5	0.00	0	0
0.300	437.0	505.0	68.00	13.6	9.5	437.0	0.00	0	0
0.150	400.0	404.0	4.00	0.8	8.7	400.0	0.00	0	0
0.075	371.0	410.0	39.00	7.8	0.9	371.0	0.00	0	0
0.063	381.5	382.0	0.50	0.1	0.8	381.5	0.00	0	0
	387.5	391.5	4.00	0.8	0.0	387.5	0.00	0	0
		TOTAL:	500.00	100		TOTAL:	1000.00	0.8	