EVALUATING THE MECHANICAL PERFORMANCE OF KUKUI SEED SHELLS AS COARSE AGGREGATES IN LIGHT WEIGHT AGGREGATE CONCRETE

BY

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23/U/GMES/0528/PE

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN IN STRUCTURAL ENGINEERING OF KYAMBOGO UNIVERSITY

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DECLARATION

I, **BAGOMBEKA ANCEL** declare that this dissertation report titled ***"EVALUATING THE MECHANICAL PERFORMANCE OF KUKUI SEED SHELLS AS COARSE AGGREGATES IN LIGHT WEIGHT AGGREGATE CONCRETE"*** is my original work and has never been submitted or presented to any university or institution of higher learning.

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APPROVAL

We the undersigned certify that this dissertation entitled ***"EVALUATING THE MECHANICAL PERFORMANCE OF KUKUI SEED SHELLS AS COARSE AGGREGATES IN LIGHT WEIGHT AGGREGATE CONCRETE"*** has been compiled under our guidance and supervision. It is now ready for submission to the Directorate of Research and Graduate Training with our approval.

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DR. SSENYONDO VICENT

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May the Lord God Bless you all abundantly!

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LIST OF ACRONYMS

ASTMC	:	American Society for Testing Materials
BS	:	British Standards
CA	:	Coarse Aggregates
HSS	:	Half Seed Shell
LWA	:	Light Weight Aggregates
Mpa	:	Mega Pascal
NaOH	:	Sodium Hydroxide
QSS	:	Quarter Seed Shell
UPV	:	Ultrasonic Pulse Velocity
UTM	:	Universal Testing Machine

ABSTRACT

Uganda's population growth, currently at 3.2% (UNhabitat, 2016), has increased the demand for residential, commercial, and industrial buildings. Concrete constitutes nearly 60% of construction materials on building sites (Aytekin et al., 2022), and aggregates contribute 70–85% of its total weight (Cement and Concrete Association of Australia, 2002). This places pressure on existing natural aggregate sources, creating the need for sustainable alternatives. Lightweight aggregates offer a potential solution, yet kukui seed shells (an organic and waste-derived option) have never been studied in the Ugandan context**,** despite their potential contribution to sustainable construction. This study adopted a combined experimental and numerical methodological framework to evaluate the suitability of kukui seed shells as lightweight aggregates. Mechanical characterization of the shells was followed by an experimental program in which normal aggregates were partially replaced with kukui seed shells at 25%, 50%, 75%, and 100% for both Half Seed Shells and Quarter Seed Shells. The resulting concrete mixes were assessed through mechanical and water absorption, Fire resistance and Thermal conductivity performance tests, while serviceability behaviour was analysed using ANSYS finite element simulations**.** The shells demonstrated satisfactory Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Los Angeles Abrasion (LAA), and soundness performance. Increasing the replacement percentage led to reductions in density, compressive strength, flexural strength, splitting tensile strength, and thermal conductivity. Quarter Seed Shell mixes generally outperformed Half Seed Shell mixes. Based on overall performance, a 50% replacement using Quarter Seed Shells is recommended, yielding a compressive strength of 25.1 MPa, thermal conductivity of 1.6 W/mK, and reduced density of 2,112 kg/m³, making it a viable lightweight concrete option for sustainable construction in Uganda.
Keywords: Experimental study, Kukui seed shells, mechanical and physical properties, durability performance, light weight aggregate concrete.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Uganda has a population base of 35 million and a high population growth rate of 3.2% making it one of the fastest-growing populations in Africa (UNhabitat, 2016). Due to this high population growth rate, the demand for structures used for accommodation, industrialization and office facilities intensifies. 60% of material used in building construction is concrete (Aytekin et al, 2022). Concrete is a composite material consisting of mainly water, aggregate and cement. It is widely used because it can be easily molded into desired shape after mixing the ingredients in certain proportions.

Coarse aggregates contribute between 70% to 85% by weight of concrete mixed (Cement and Concrete Association of Australia, 2002). With a high demand for building construction, the need for coarse aggregates rises resulting in a strain on existing normal coarse aggregate sources. This necessitates alternative sources of coarse aggregates (George and Revathi, 2020). One alternative coarse aggregate is Light Weight Aggregates. One of the advantages of Light Weight Aggregates Concrete is their ability to reduce the overall self-weight of structures (Agrawal et al., 2021) creating lighter high-rise structures when used as an alternative to normal coarse aggregates. There are different types of light weight aggregates that are used in Light Weight Aggregate Concrete; these include Natural LWA (Pumice), Artificial / Manufactured LWA (like steel slug) and Organic LWA (like kukui seeds)

Kukui (Hawaii) or Kabaka Anjagala, is a flowering tree (normally it grows up to 20 m height) belonging to the Euphorbiaceae family. Its species name is Aleurites Moluccanus. The tree is native to the Indo-Malaysia region and became one of the world's great domesticated multipurpose trees (Juara, 2023) In Uganda, it is commonly known as "*Kabaka*

Anjagala". "*Kabaka Anjagala*" translates to the "King loves me". The trees which were imported from India derive their local name from the local subjects (Ssaza Chiefs) whom these trees were given to by Kabaka of Buganda, Sir Fredrick Mutesa, during a visit.

The Kukui tree can be found in different areas of Kampala especially around kabakanjagala road. The level of flowering varies but it has a minimum of two seasons per year (Missouri Botanical Garden, 2024) The tree takes four years to grow and start bearing significant fruit (pfaf,2020) It bears around 80kgs of seeds per tree (Fu et al., 2023). This amounts to approximately 90 trees being planted in a hectare.

An average seed yields about 10-40% of oil (Shaah et al., 2021). Oil derived from the seeds provides useful material for biodiesel, varnish, soap and pharmaceuticals. After removal of the oil, the remaining seed cake can be used for fertilizer or animal feeds (Fu et al., 2023) or as feedstock for biomass. The kukui seed shells can also be an alternative renewable energy source. (Cavron, 2022). From a hectare of land, one can collect 4 – 6 tonnes of kukui seed shells per year.

Information about the distribution of the candlenut trees in Uganda is currently unavailable. Fortunately, KCCA managed to map different tree species in Kampala and it was discovered that there were 466 trees in Kampala (Kcca, 2024). These trees were randomly planted hence utilizing the various advantages of the kukui tree isn't being done. One of the companies that has utilized this tree is "African Power Initiative" who have been in the business of planting, buying and extracting the various benefits of these seeds from 2009. They deal in bio-diesels, briquettes and many other products. Currently, they have a biodiesel production facility in Mukono district (Uganda) with capacity to produce 60,000 litres of biodiesel per day which amounts to about 18million litres per year. This would lead to a production of about 36,000 tonnes of kukui seed shells which can also be utilized in concrete.

One of the prerequisites for aggregates to be light weight is that they should have a particle density which is less than 2000kg/m^3. (EN 1992-1-1:2004). The kukui seed shell density is 1140 kg/m^3 (Eky et al., 2023). This puts kukui shells under the category of light weight aggregates. Apart from reducing the self-weight of the structure, the concrete with these seeds improves the thermal insulation properties of the Light Weight Aggregates. These are just a few examples of how the kukui seed shells will improve on the mechanical properties of concrete.

1.2 Statement of the Problem

Uganda's population growth currently stands at 3.2% (UNhabitat, 2016), leading to an increasing demand for residential, commercial, and industrial buildings. Concrete constitutes approximately 60% of the materials used in construction, and coarse aggregates contribute 70–85% of its total weight. According to the Uganda Bureau of Statistics (UBOS) construction price index, the demand for aggregates increased by 4% between February 2023 and February 2024 (UBOS, 2024). However, despite this increase in demand, production from several quarry sites has remained relatively constant over the past five years, reflecting a growing demand–supply imbalance. Rising aggregate prices and reports of reduced quarry output in some districts further indicate increasing strain on natural normal aggregate sources.

This situation highlights the need for alternative coarse aggregates to supplement the existing natural sources. Lightweight aggregates offer a viable option, with the added advantage of reducing the self-weight of structural elements. Kukui seed shells, an organic lightweight aggregate, present a potential sustainable alternative but have not yet been explored within the Ugandan context. Their utilization in concrete could reduce dependency on natural normal aggregates while having a positive impact on the community and improving on some properties of the concrete it in incorporated in.

1.3 Objectives of the study

1.3.1 Main Objectives

To investigate the performance of kukui seed shell size and replacement percentage as lightweight concrete.

1.3.2 Specific Objectives

i. To determine the mechanical properties, physical properties and sizes of kukui seed shells to be used in concrete

ii. To determine the mechanical properties of concrete that constitutes kukui seed shells

iii. To determine the water absorption, fire resistance and thermal conductivity performance of concrete that constitutes kukui seed shells

iv. To use finite element analysis to investigate the serviceability performance of a concrete structural element that makes up kukui seed shells under loading

1.4 Research Questions

i. What are the physical properties and mechanical properties of the kukui seed shells? What is the appropriate size of kukui seed shell to be used in concrete? The physical properties include the kukui seed shell's density, partical size distribution, flakiness and water absorption value. The mechanical properties include the kukui seed shell's

Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV) and Los Angeles Abrasion value (LAA). The kukui seed shell sizes tested where Quarter Seed Shells (Maximum partical size of 14mm) and Half Seed Shells (Maximum partical size of 20mm).

ii. How does adding kukui seed shells to concrete affect it's mechanical properties? The mechanical properties of the concrete that has the kukui seed shells as a constituent include Compressive strength, Flexural Strength, Splitting Tensile Strength and Modulus of Elasticity.

iii. How does adding kukui seed shells to concrete affect its Water Absorption, Fire resistance and Thermal Conductivity performance?

iv. To what extent does the use of kukui seed shells in concrete, affect the serviceability performance of a structural element as modeled through Finite Element Analysis?

1.5 Justification

The research explores the potential of using kukui seed shells as an alternative to other Light Weight Aggregates, which aligns with SDG 7 which encompasses Affordable and Clean Energy (United Nations, 2015) where Organic Light Weight aggregates are sustainable options compared to Natural and Manufactured Light Weight Aggregates.

The research promotes waste utilization which aligns with the need to reduce pollution under enhancing Natural Resources, Environment, Climate Change, Land and Water Management to sustainably increase household incomes and quality of life (World Bank, 2020)

The study contributes to the body of engineering knowledge by assessing the properties of kukui seed shells and their effects on the properties of concrete it is utilized in which aligns with SDG 9 which encompasses Industry, Innovation and Infrastructure (United Nations, 2015)

1.6 Significance

Environmental Sustainability: The use of kukui seed shells offers a sustainable solution for repurposing waste generated from the oil extraction process. By diverting the kukui seed shells from landfills and incorporating it in concrete, the study contributes to waste reduction and promotes the culture of reducing the accumulation of waste from the oil extraction process, reusing the seed shell waste and recycling the seed shells in different concrete works.

Enhanced mechanical properties of concrete: The use of kukui seed shells offers an improvement on properties of concrete like workability (Rangan, 2022). It is also noted that the use of organic material in concrete improves its insulation properties and resistance to freezing (Sisman et al., 2011)

Light weight structures: The unit weight of kukui shell density is 1140 kg/m3 (Eky et al., 2023) while that of normal aggregates is above 2000kg/m3 (EN 1992-1-1:2004). Therefore, using kukui seed shells in concrete leads to development of lighter structures compared to when one uses normal aggregates. The lighter the structural members, the more freedom an engineer has to build taller structures.

Socio-Economic Impact: During the extraction, sorting, preparation and distribution processes, the livelihoods of the communities involved in these activities improves. It has a positive impact to the lives of the community as some are employed and others are encouraged to look at waste as a source of income not as a useless item.

Future research potential. From analysis of the seed shell properties, new areas where the seed can be utilized can be explored

Provide an alternative to already existing Light Weight Aggregates. Light Weight Aggregates are an alternative to normal coarse aggregates. They can be used in areas which would want to maximize their properties. Kukui seed shells are Organic Light Weight Aggregates that can also be utilized in areas where their properties are an advantage.

1.7 Scope of the Study

This study was carried out in Sheema district (Western Uganda) due to the accessibility of the kukui seed shells and the increased construction of structures in the area.

This study was aimed at determining the mechanical and physical properties of the kukui seed shells, determining the mechanical properties of concrete that uses kukui seed shells, determining the durability performance of the concrete that uses kukui seed shells and to develop a structural model to explore the performance of concrete using kukui seed shells in light weight aggregate concrete

This study took 11 months. It ran from August 2024 to June 2025

1.8 Conceptual framework

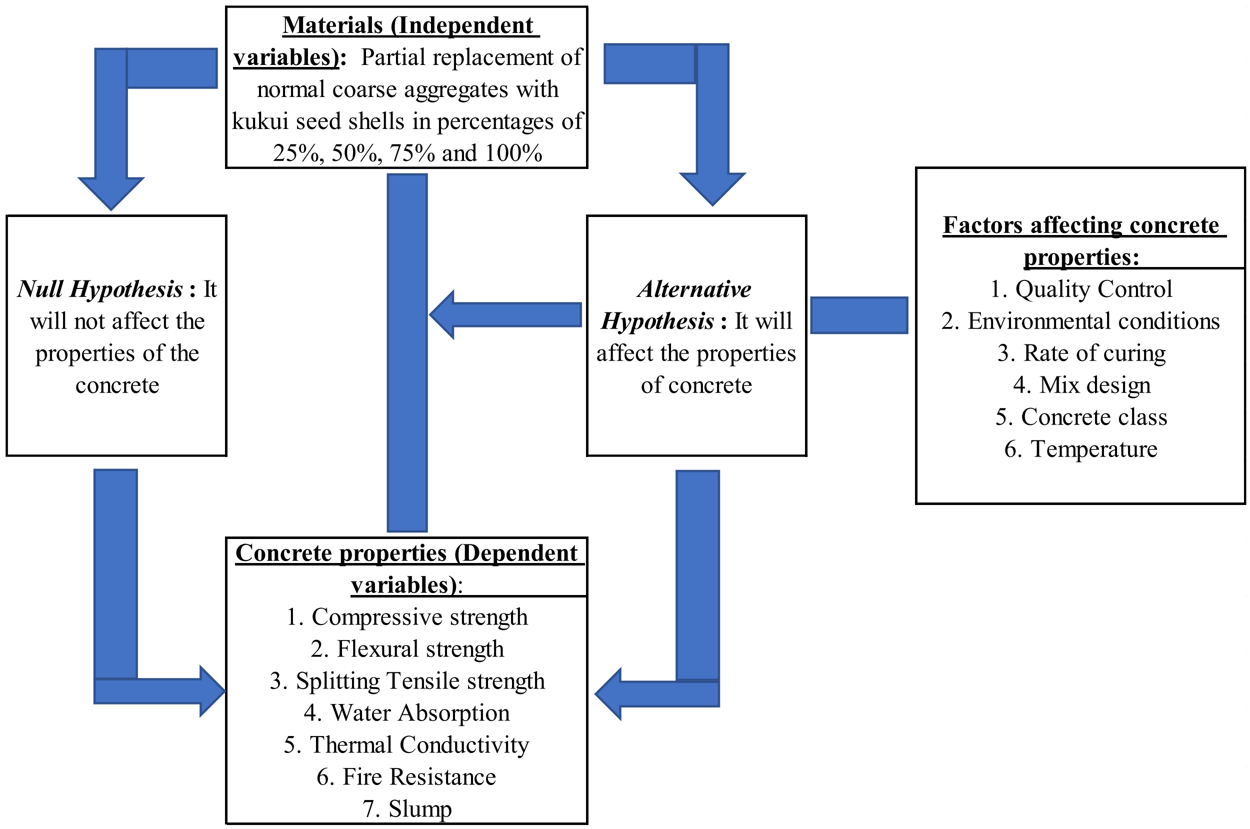


Figure 1- 1: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter provides a wide range overview of the research conducted on light weight aggregates. It covers various aspects related to light weight aggregates including their history, properties, their types, their applications and their advantages compared to normal aggregates.

2.2 Theoretical Review

Light weight aggregates are one type of aggregates used in concrete in order to reduce the overall weight of the concrete. This kind of aggregate has a low bulk specific gravity because of its cellular or highly internal porous microstructure, which contributes to its light weight (Wang et al., 2020).

2.2.1 History of light weight aggregates

Production of lightweight aggregate from natural sources dates back to pre-Roman times, when it was utilized to construct Rome's aqueducts, Pantheon, and Collosseum (Durga et al, 2018). In the early 20th century, during the second industrial revolution, during the production of iron, blast furnace slags (a bi product of the manufacturing process), was used in roads and railway construction (Thienel et al, 2020). From that time, different types of artificial aggregates were developed to suite the need at the time of construction. Regrettably, the majority of the original artificial aggregate manufacturing facilities failed, possibly as a result of market inaccessibility, feedstock quality control problems, emission problems, and excessive production costs.

2.2.2 Types of light weight aggregates

i. Natural Aggregates (Psu, 2019)

These are aggregates that are found in their natural state. They are usually found around areas with volcanic activity. They have limited applications because their properties are known and cannot be modified. Some examples of these aggregates include:

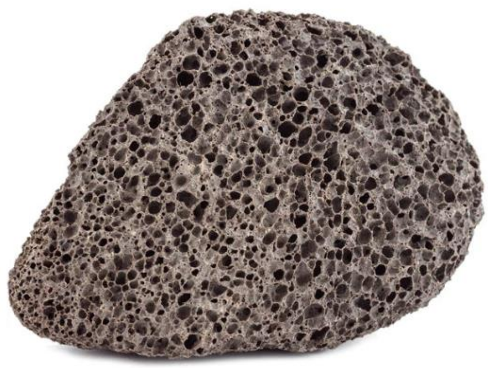



Figure 2- 1: Pumice and Scoria aggregates

ii. Artificial Light Weight Aggregates (Clarke, 2002)

These are mainly manufactured. They depend on the requirements of the market for example it can be manufactured for sound insulation but not for structural purposes. These are made from by-products like fly ash and blast furnace slag as well as from natural raw materials including expanded clay, shale, slate, etc. Below is a list of some artificial light weight aggregates and their manufacturing processes:

Table 2- 1: Artificial light weight Aggregates and their manufacturing process

Aggregate Name	Constituent
Foamed Slag	Foamed slag
Leca/Fibo	Expanded clay
Pellite	Blast furnace slag
Granulex	Expanded slate
Liapor	Expanded slate

iii. Organic Material (Bertoldo et al., 2023)

The organic materials used are usually a bi-product of a manufacturing process. The use of Corncobs, rice husks, straw and wood organic waste in concrete has already been investigated on. They have been found out to have positive results in weight reduction of the concrete, utilization of organic waste (this reduces the strain on waste collection and disposal) and in reducing the environmental impact of the construction sector. Kukui seed shells fall under organic materials that can be used as a light weight aggregates.

2.2.3 Current research that has been carried out on Light Weight Aggregate Concrete

Under this section, we shall explore the variations of different properties of the different types of Light Weight Aggregates (LWA). For the natural aggregates, we shall look into research that was carried out to evaluate the "Partial Replacement of Pumice Stone in Concrete as Coarse Aggregate Material" (Sagar et al., 2021). Additionally, in regards to artificial/ Manufactured LWA, we shall look at "Utilization of steel slag as partial replacement for coarse aggregate in concrete" (Mohamed Elwi Mitwally et al., 2024).

Furthermore, for organic LWA, we shall look into the "Exploratory study on partial replacement of coarse aggregate by talipot palm seed" (S and George, 2016). This will aid in comparing the different results the different authors came up with.

Mechanical properties of the different LWA

1. Density of the LWA

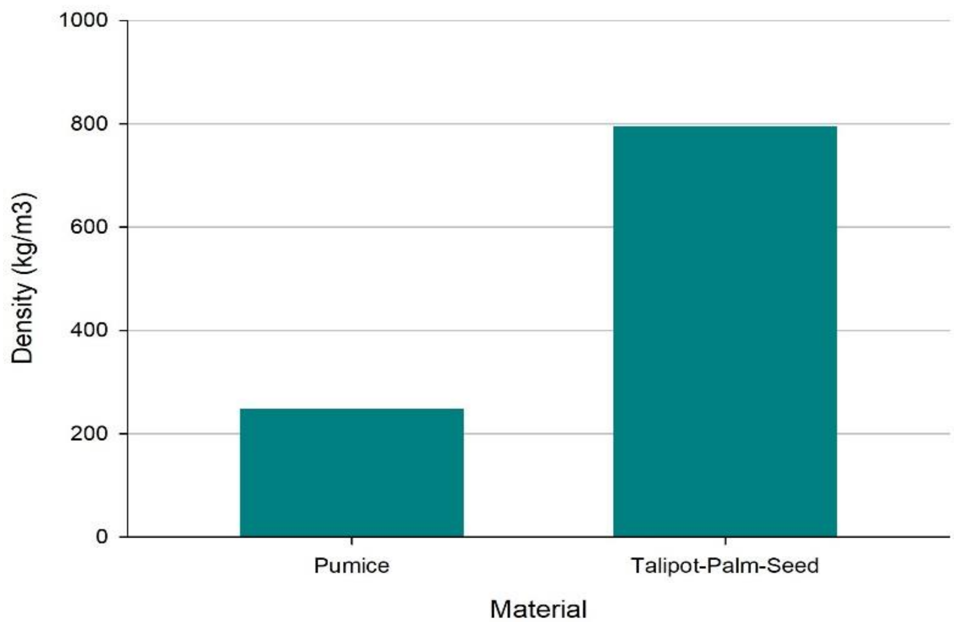


Figure 2- 2: Densities of Pumice (Sagar et al., 2021) and Talipot Palm Seed (S Kavitha et al., 2017)

Both the Pumice and Talipot Palm Seeds have densities below 2000kg/m3 which categorizes them as LWA. **Figure 2-2** above shows the densities of Pumice and Talipot Palm Seeds respectively. The Talipot Palm Seeds are denser than the Pumice rocks. This can be attributed to the high number of voids within the Pumice rocks (S Kavitha et al., 2017)

2. Water Absorption

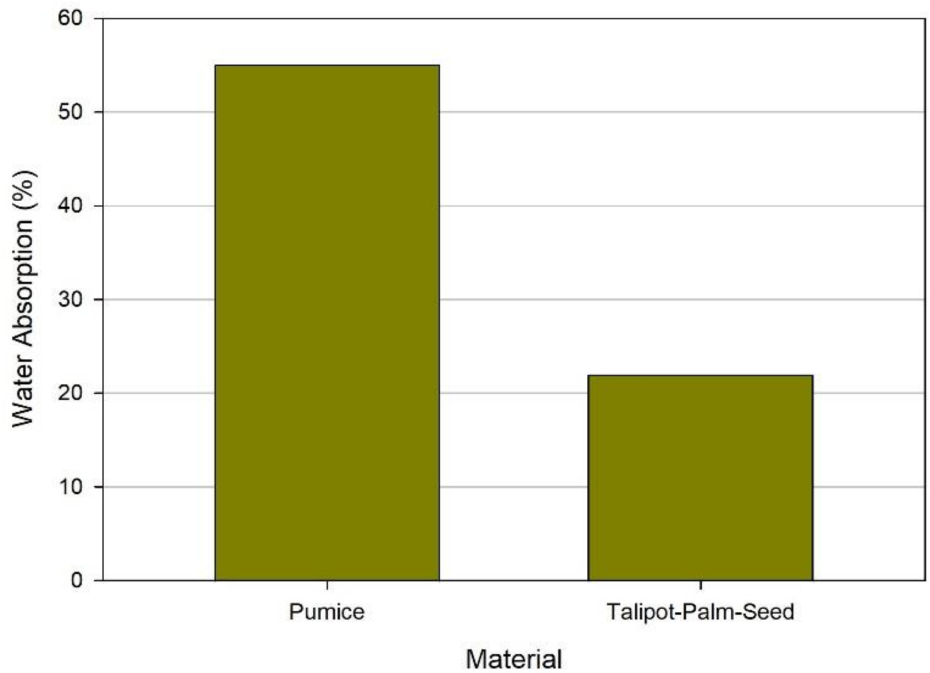


Figure 2- 3: Water Absoption Values of Pumice (Sagar et al., 2021) and Talipot Palm Seed (S Kavitha et al., 2017)

Both the Pumice and Talipot Palm Seeds have Water Absorption values of above 20%. **Figure 2-3** above shows the Water Absorption values of Pumice and Talipot Palm Seed respectively. The Pumice has a higher Water Absorption value (55%) compared to the Talipot Palm Seeds (22%). This can be attributed to the high number of voids within the Pumice rocks (Sagar et al., 2021) which leads the rock to absorb more water.

3. Slump Test

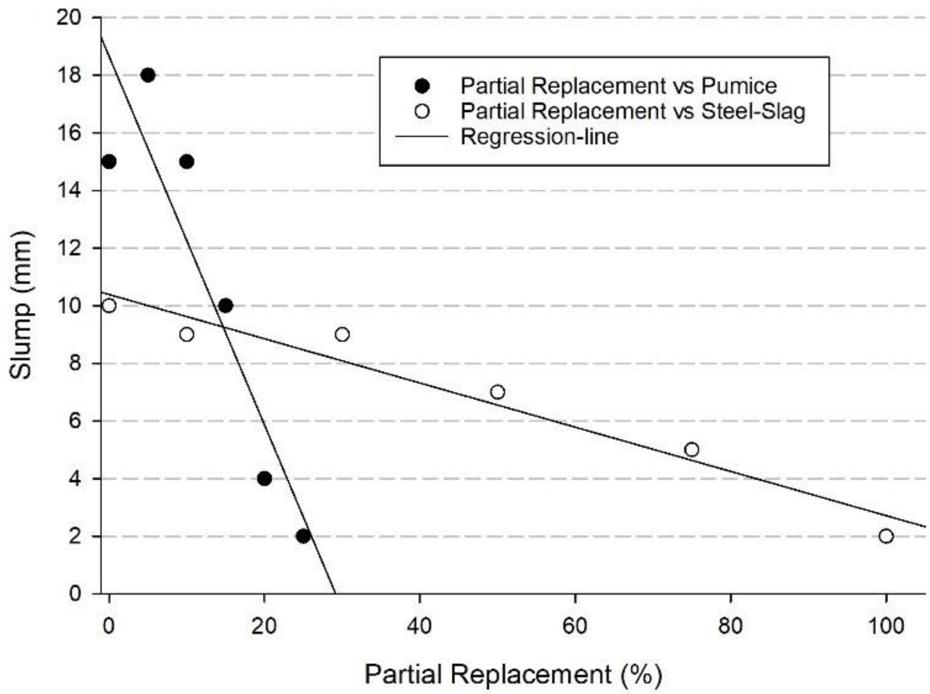


Figure 2- 4: Variation of Slump results with different partial replacement percentages for Pumice (Sagar et al., 2021) and Steel Slag (Mohamed Elwi Mitwally et al., 2024)

Figure 2-4 above shows the Variation of slump results with different partial replacement percentages for Pumice and Steel Slag. Both the Pumice and Steel Slag have a reduced slump with an increase in their percentages with the Pumice having a steeper drop compared to the Steel Slag. This steeper drop can be attributed to the high number of voids within the Pumice rocks (Sagar et al., 2021) which leads the wet concrete to become semi dry as the percentage of pumice increases. The semi-dry nature affects the workability of the wet concrete. The pumice absorbs more water hence a special calculation for the water/ cement ratio will be needed to enable the Pumice to be properly saturated.

4. Compressive strength

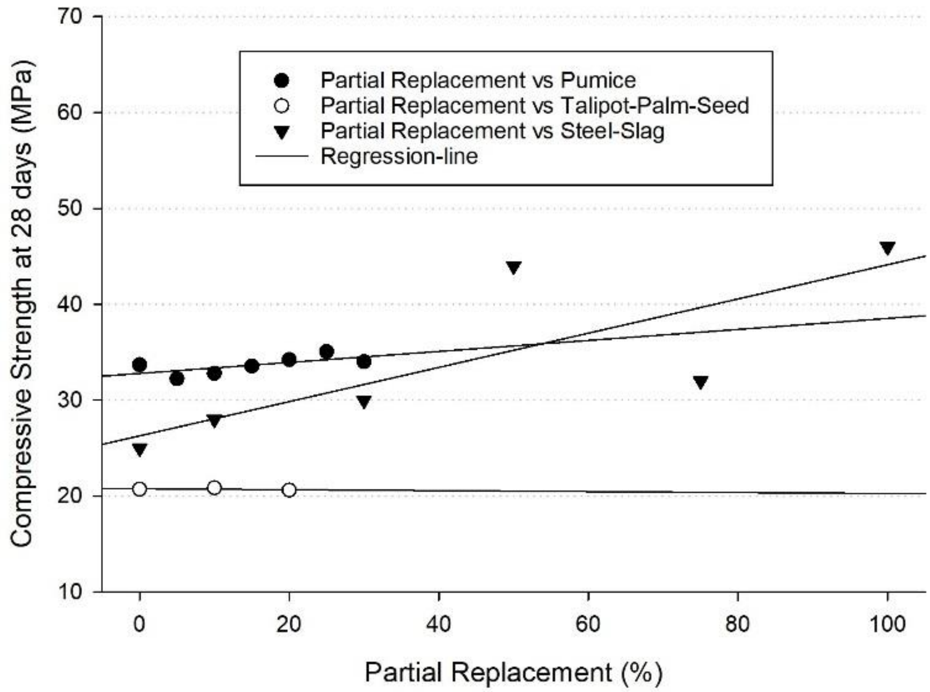


Figure 2- 5: Variation of compressive strength Vs different partial replacement percentages for Pumice (Sagar et al., 2021), Steel Slag (Mohamed Elwi Mitwally et al., 2024) and Talipot Palm Seed (S Kavitha et al., 2017)

Figure 2-5 above shows the Variation of compressive strength with different partial replacement percentages for Pumice, Steel Slag and Talipot Palm Seed. The results for the Pumice and Steel-Slag show an increase in compressive strength with increase in their percentages. The Talipot Palm Seed concrete line is relatively flat in nature meaning that the compressive strength is constant with increased their percentages.

5. Splitting tensile strength

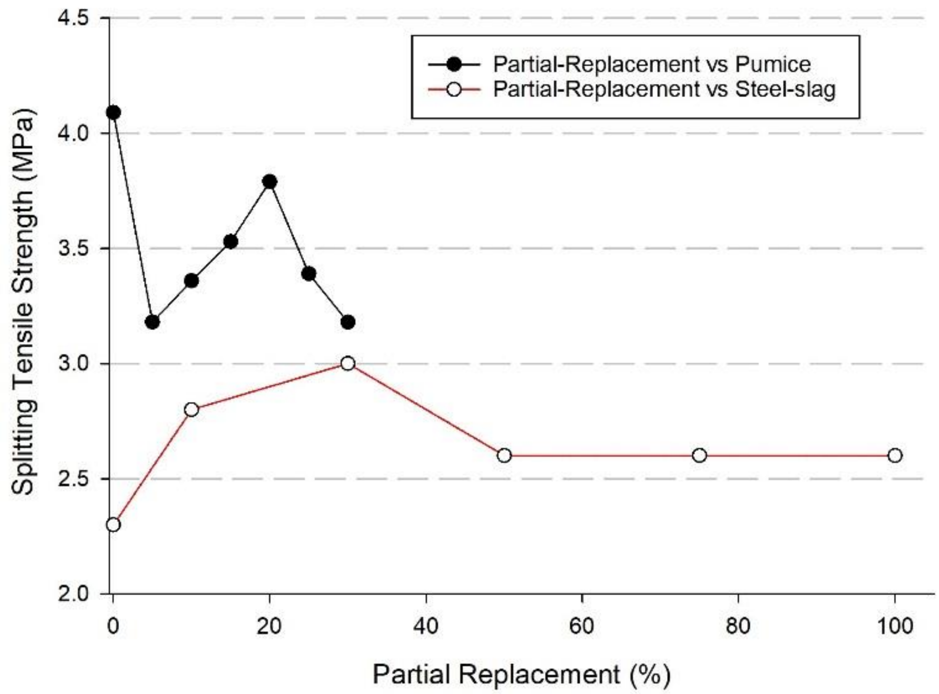


Figure 2- 6: Variation of Splitting Tensile Strength Vs different partial replacement percentages for Pumice (Sagar et al., 2021) and Steel Slag (Mohamed Elwi Mitwally et al., 2024)

Figure 2-6 above shows the Variation of Splitting Tensile Strength with different partial replacement percentages for Pumice and Steel Slag. The results for the Pumice show an increase in Splitting Tensile Strength until 20%, after that, the splitting tensile strength keeps falling until 30%. The Steel-Slag has an increase in Splitting Tensile Strength until 30% thereafter it falls at 50% where it remains constant until 100%.

2.2.4 Hindrances to the use of light weight aggregates

1. **Scarcity:** In relation to natural aggregates, Pumice is usually located around volcanic areas making it hard to access in most parts of Uganda. Since Steel-Slag is a by-product of a manufacturing process, it can only be accessible in areas with such industries.
2. **Cost:** Due to Pumice and Steel-Slag's scarcity, they are expensive to acquire and might not be seen as a profitable venture for investors.
3. **High water absorption value**: The natural (Pumice), artificial (Steel-Slag) and organic (Talipot Palm Seeds) LWAs have high water Absorption values which leads to an imbalance in the water cement ratio hence increased reduction in concrete strength and the need for experienced labor during casting.
4. **Not environmentally sustainable**. Pumice is a non-renewable material that needs to be mined in order to be gotten. The mining activities have negative effects on the environment and with time, pumice will become scarce and even more expensive. Steel-Slag is a by-product of a manufacturing process; these industries release harmful gases which affect the ozone layer negatively.
5. **Insufficient information about most LWA**. This field is still a virgin area which needs exploiting. More studies should be carried out on LWAs so that the various advantages can be harnessed and used in the field of engineering.

2.2.5 Applications of Light weight Aggregates

a. It is used for screeds and thickening. When the floor or roofs require thickening or smoothness it can be used to achieve it easily.

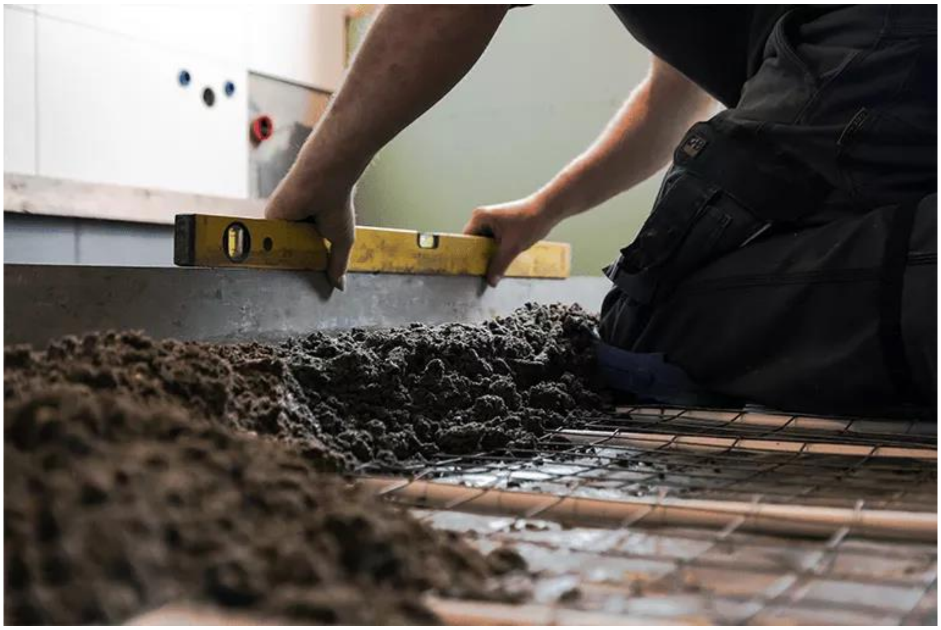


Figure 2- 7: Leca lightweight aggregate concrete as a fill material

b. Lightweight aggregate concrete can be used for casing structural steel to protect it against fire and corrosion.
c. It can also help in decorations for architectural purposes.

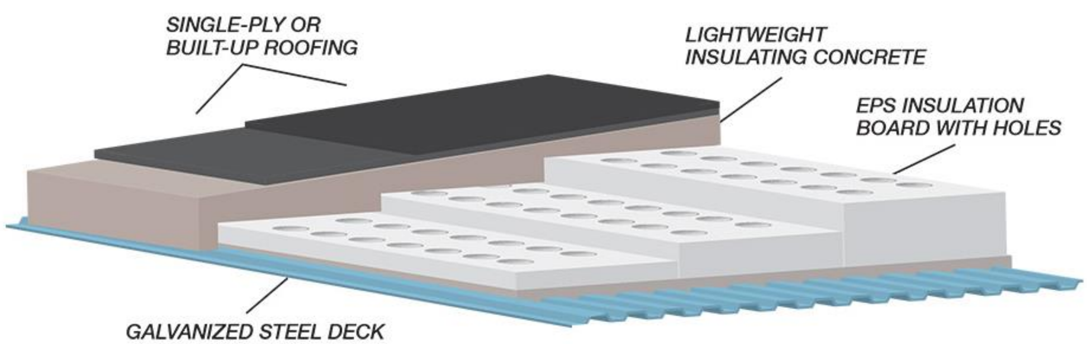


Figure 2- 8: Section of roof insulation layers done by Texas Roof Management Inc.

d. It can be used for heat insulation purposes on the roofs.
e. It can be used to insulate water pipes.
f. Lightweight aggregate concrete can be used for the construction of partition walls and panel walls in frame structures.

g. It can be used to create general insulation of walls.

h. It is also used to get surface rendered for external walls of small houses.

i. It can be used for reinforced concrete beams, columns and slabs.

2.2.6 Reasons why Light Weight Aggregates should be considered to be used in concrete

i. They are cost effective in some cases

ii. Reduced Structural weight. Due to most of the LWAs having low densities, they reduce on the weight of the structure hence leading to economical design.

iii. Improves thermal and acoustic performance of concrete

iv. Better internal curing of concrete since they release water slowly into the concrete

v. Increased demand for LWA would make it a good business opportunity

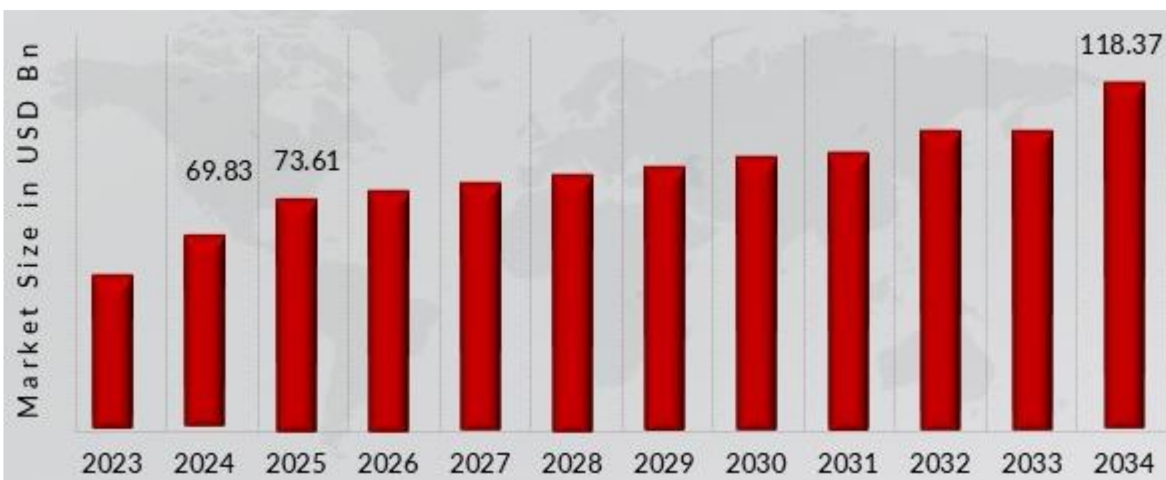


Figure 2- 9: Graph showing increase in demand for light weight aggregates in the United States (Market, 2024)

2.3 Empirical Review

Kukui Nuts and Kukui Seed have different Properties as an organic material to replace natural light weight aggregates as discussed below;

2.3.1 Mechanical and physical properties of kukui seed shells

i. **Density**: The kukui seed shell has a density of 1140 kg/m^3 (Eky et al., 2023).

ii. **Shape**: It is elliptical in shape and has a hard skin. The thickness of the seed shell is about 3-5 mm, and it has brown or blackish in colour. (Leke et al., 2022)

2.3.2 Natural composition of kukui seed shells

Table 2- 2: Natural composition and solubility results of kukui shells (Kafama,2020)

No.	Component	Content (%)
Natural composition		
1	Pentose	14.22
2	Lignin	54.46
3	Other	31.32
Solubility		
4	Extractive:	
5	Solubility in water	1.96
6	Solubility in hot water	6.18
7	Solubility in benzene alcohol	2.69
8	Solubility in NaOH 1%	17.14
9	Ash	8.73

2.3.3 Existing/ Previous Research on mechanical properties of concrete that uses Kukui Seed shells as a material replacement.

Currently, the partial replacement has been done until 30%. None of the authors state why they stopped at 30%. It is only mentioned that they only checked the Compressive strength (as a mechanical test) because it is the most important mechanical property of concrete (Rangan, 2022). Since they did not investigate other properties such as tensile strength, flexural strength, water absorption or thermal properties, they could not justify whether 30% was an optimum, a failure point, or simply a convenient experimental limit. Though incorporating the kukui seed shells in concrete reduced its compressive strength, it is unknown what the effect the seed shell properties have on mechanical properties of concrete for example Flexural Strength and Spitting Tensile Strength. This is why the author explored other percentage replacements and their effects on all mechanical properties.

Potential Utilization of Candlenut Shell Waste as Coarse Aggregate Replacement in Concrete (Rangan, 2022).

a. Mechanical properties of Candlenut concrete

    1. Wet Concrete

        a. Slump Test

        Tests carried out on concrete without concrete gave a slump of 11cm while those with partial replacement using Candlenut gave an average value of 10cm.

    2. Dry Concrete

        a. Compressive Test

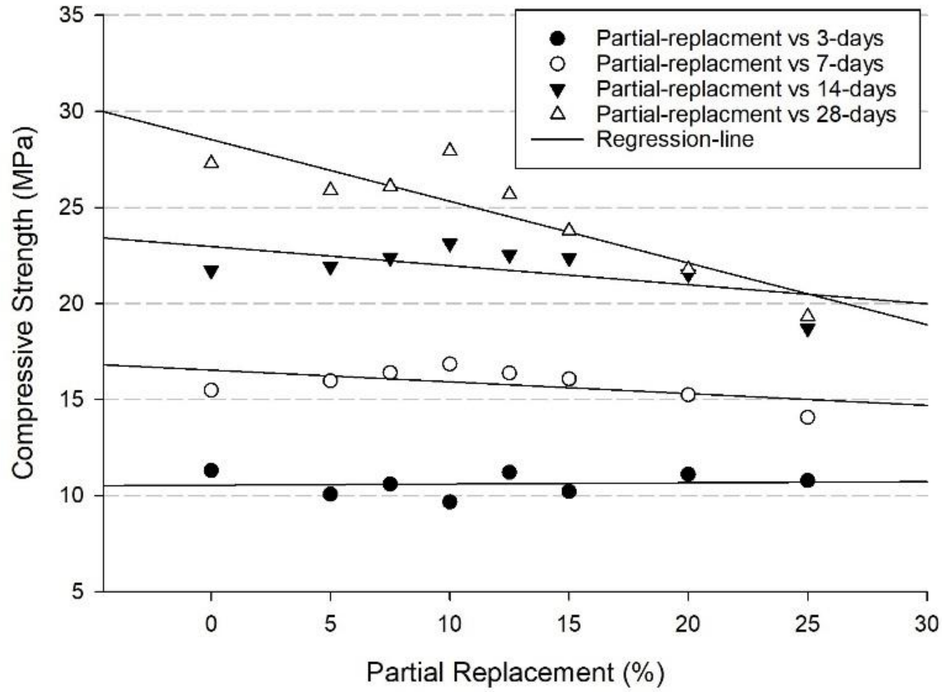


Figure 2- 10: Variation of Compressive Strength with different partial replacement percentages for Candlenut shells at different days (Rangan, 2022)

Figure 2-10 above shows the Variation of Compressive Strength with different partial replacement percentages for Candlenut shells with time. Generally, it is observed that the Compressive Strength of the concrete reduces with an increase in the percentage of Candlenut shells added. Furthermore, the 10% partial replacement percentage produces higher compressive strengths for 7 days, 14 days and 28 days compared to the control concrete.

i. Determining the value of concrete compressive strength with variation of kukui shell percentages applied to a concrete mix in a plate of size 50cm x 25cm x 12cm using a non-destructive test using Ultrasonic Pulse Velocity (UPV) (Mushar, 2022)

a. Mechanical Properties of the concrete

1. Weight

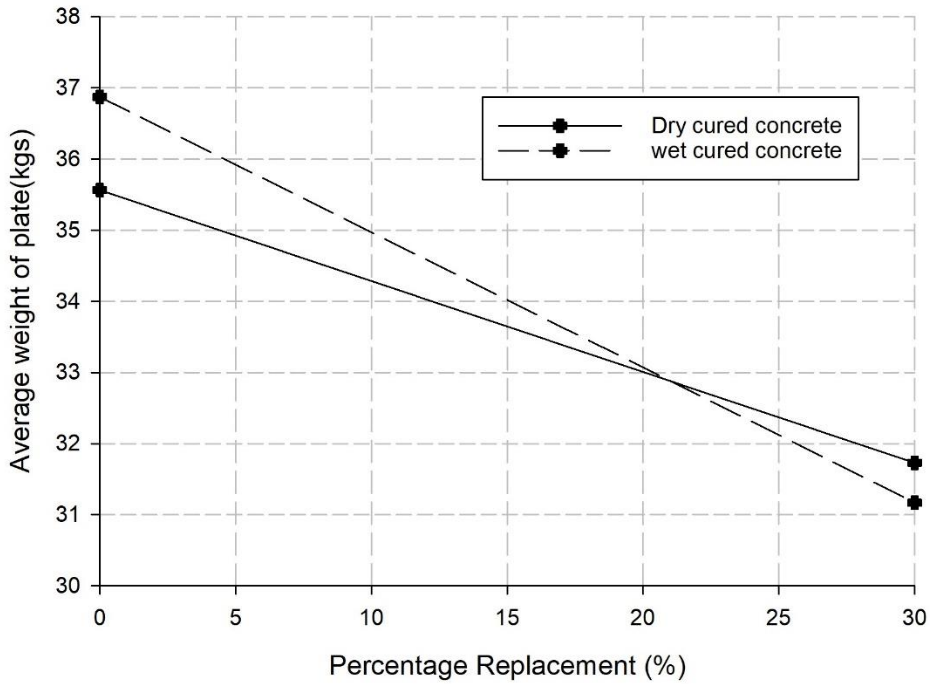


Figure 2- 11: Variation of weight of plate with partial replacement of crushed seeds

It was observed that there was a **11%** reduction in weight of **dry cured** concrete with 0% crushed seed to 30% crushed seeds. Additionally, there was a **15%** reduction in weight of **wet cured** concrete with 0% crushed seed to 30% crushed seed. Generally, wet cured concrete is heavier than dry cured concrete.

2. Compressive Strength

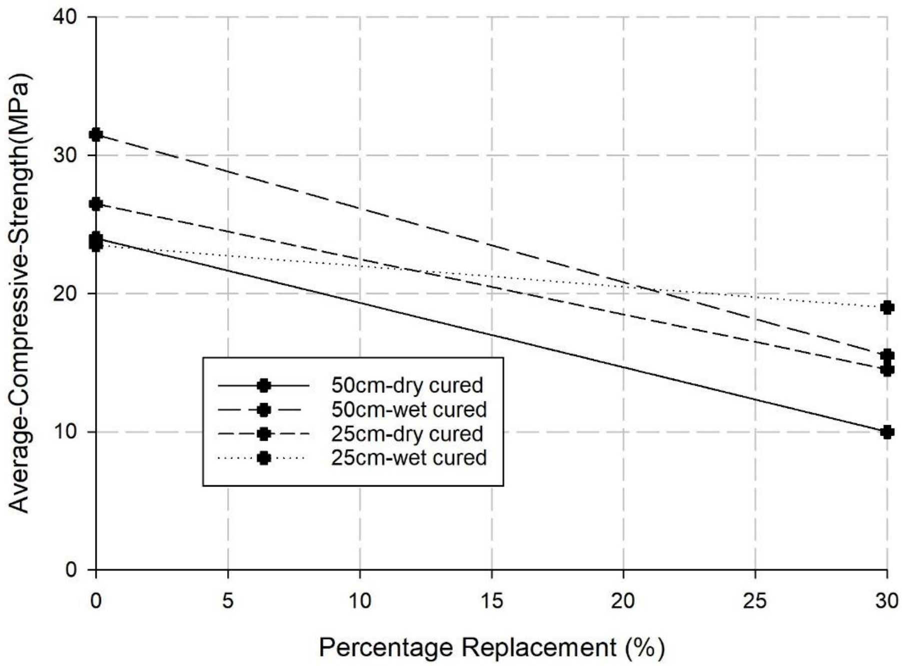


Figure 2- 12: Variation of Compressive strength of plate with partial replacement of crushed seeds

The concrete compressive strength class designed for was class 2 – k-300 (SNI 03-2847-2002) which is 24.9MPa. It was observed that there was a **58%** reduction in compressive strength of **dry cured** concrete with 0% crushed seed to 30% crushed seeds with **50cm** plates. Additionally, there was a **51%** reduction in compressive strength of **wet cured** concrete with 0% crushed seed to 30% crushed seed with **50cm** plates. It was also observed that there was a **45%** reduction in compressive strength of **dry cured** concrete with 0% crushed seed to 30% crushed seeds with **25cm** plates. Also, there was a **19%** reduction in compressive strength of **wet cured** concrete with 0% crushed seed to 30% crushed seed with

25cm plates. Generally, wet cured concrete has a higher compressive strength that dry cured concrete.

Determining the value of concrete compressive strength with variation of kukui shell percentages applied to a concrete mix in a plate of size 50cm x 25cm x 12cm using a a destructive test using a Universal Testing Machine (UTM) (Sampebulu, 2020)

a. Mechanical Properties of the concrete

Dry concrete

1. Weight

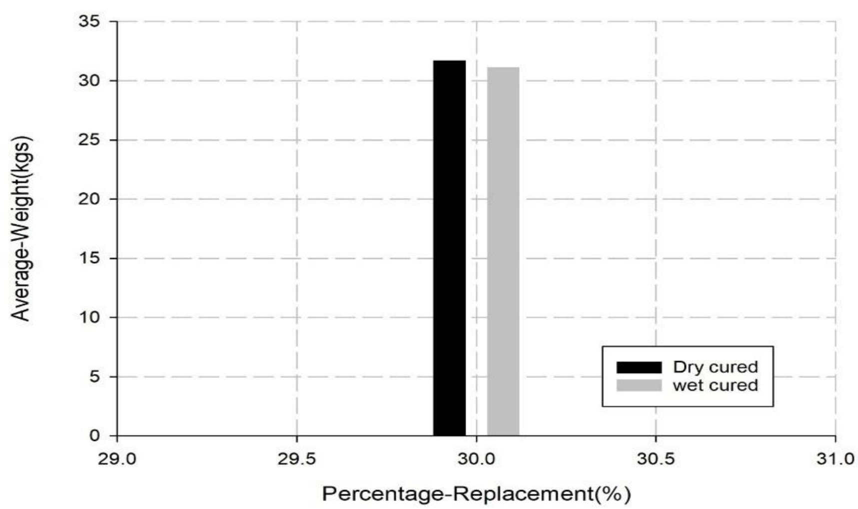


Figure 2- 13: Variation of weight of plate with 30% partial replacement of crushed seeds

It was observed that the **wet cured** 30% crushed seed concrete weighed **1.7%** less than the **dry cured** concrete.

2. Compressive Strength

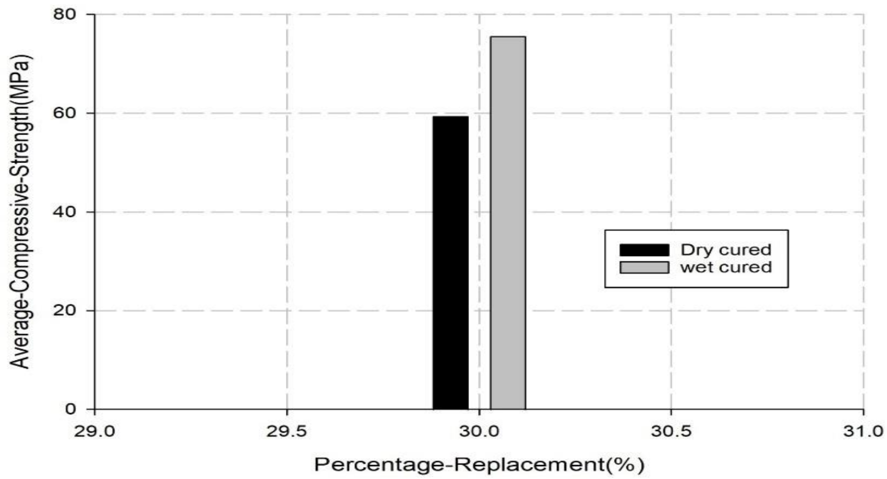


Figure 2-14: Variation of compressive strength of plate with 30% partial replacement of crushed seeds

The concrete compressive strength class designed for was class 3 – k-500 (SNI 03-2847-2002) which is 41.5MPa. It was observed that the **wet cured** 30% crushed seed concrete had **21%** less compressive strength than the **dry cured** concrete.

2.3 Gaps in the research

i. Lack of physical and mechanical tests on the kukui seed shells and coarse aggregates. An example of this is there is no comparison between any sieve analysis carried out on coarse aggregates used in the experiment verses the kukui seed shells used. The author carried out mechanical and physical tests on the kukui seed shells and coarse aggregates and results were compared.

ii. Lack of durability performance tests done on the concrete incorporated with the kukui seed shells ie thermo-conductivity, fire resistance and water absorption tests. The author carried out the mentioned tests on the concrete and from the results analyzed, draw recommendations and conclusions

iii. The current research only carries out tests until partial replacement of 30%. The author expanded on this range by carrying out partial replacement of 0% (fully aggregates), 25%, 50%, 75% and 100% (fully kukui seed shells). From analysis of the mechanical tests done on these samples, conclusions and recommendations were drawn accordingly.

iv. Currently, there is no research highlighting the morphology of the kukui seed shells. This was carried using a Scanning Electron Microscope (SEM) which aided in the analysis of the arrangement of particals of the seed shell.

Reasons why kukui seed shells are a viable option compared to other LWAs

1. **More accessible** compared to Manufactured and Natural LWA. Pumice rocks can only be obtained in specific parts of the country (mainly near inactive volcanos) while kukui trees can be grown in most parts of the country.
2. **Positive impact on the environment.** These trees help absorb most greenhouse gases which reduce on the effect of global warming.
3. **Positive impact to the community involved.** The entire community is involved from planting, to extraction and final processing of the shells. This improves the overall welfare of the community.

4. **Various sources of income.** Apart from being used to extract oil, these trees provide timber, briquettes and many other benefits. Farmers can earn additional income from being paid by Carbon Offset Programs that pay individuals for planting trees.

Effects of organic material on the mechanical properties of concrete

a. Reduction in concrete density. It was discovered that a 40% partial replacement of coarse aggregates with the coconut shell waste led to a density reduction of 7%. (Javadi Pordesari et al., 2025) This was mainly because the seeds are of low density.
b. Improvement in insulation (sound and thermal) due to their porous and fibrous texture that traps air which is a poor conductor, making it difficult for sound or heat to move through the concrete. (Wijesinghe et al., 2025).
c. Internal curing. internal curing results in reducing water consumption, improving concrete homogeneity and reducing surface cracking. (El-Hawary and Al-Sulily, 2020)
d. Reduction in compressive strength. A study observed that with an increase in palm seed kernel in concrete, the compressive strength of the concrete reduced (Odeyemi, 2021). This is due to many reasons ranging from low seed strength, micro cracks in the concrete, increased voids in concrete and so on.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Materials and Methods

3.1.1 Research design

The maximum nominal size for aggregates to be used in reinforced concrete is 20mm (cite). In the study, it was discovered that Quarter Seed Shells have a maximum partical size of 14mm while Half Seed Shells have a maximum partical size of 20mm. This lies within the recommended range for aggregates to be used in concrete so the kukui seed shells used can be used in reinforced concrete.

A total of 210 standard concrete cubes (150 × 150 × 150 mm), 30 standard cylinders (100 mm × 200 mm), and 30 beams (150 × 150 × 750 mm) were cast with varying partial replacement percentages of Quarter Seed Shells (QSS) and Half Seed Shells (HSS) at 0%, 25%, 50%, 75%, and 100%. For each partial replacement mix, six cubes were prepared for compressive strength tests at 7 and 28 days. An additional three cubes per mix were cast for each of the following 28-day tests: thermal conductivity, fire resistance, modulus of elasticity, water absorption, and X-ray analysis. Furthermore, three beams and three cylinders were cast for flexural and splitting tensile strength tests, respectively, at 28 days. The selected sample sizes were designed to allow reliable estimation of the mean, standard deviation, and 95% confidence intervals for each property tested.

Strict control measures were implemented to ensure replicability. The sources and properties of all materials used are detailed in this report. Batching was conducted by weight, and mixing was performed using a 1-bag capacity concrete mixer operating at a speed of approximately 18 rpm. Fresh concrete was placed into standard moulds (cubes, cylinders, and beams) in layers and compacted appropriately. After 48 hours, the specimens were demoulded and cured in a water tank under controlled conditions until the designated test ages. All tests were conducted in accordance with relevant British Standards, and raw test data are presented in the appendices.

After analysis of the results, a model was developed in ANSYS to compare the serviceability performance of kukui seed shell concrete to normal concrete under loading conditions. The experiments were carried out at the Material's Laboratory of Kyambogo University and the Physics Department of Makerere University

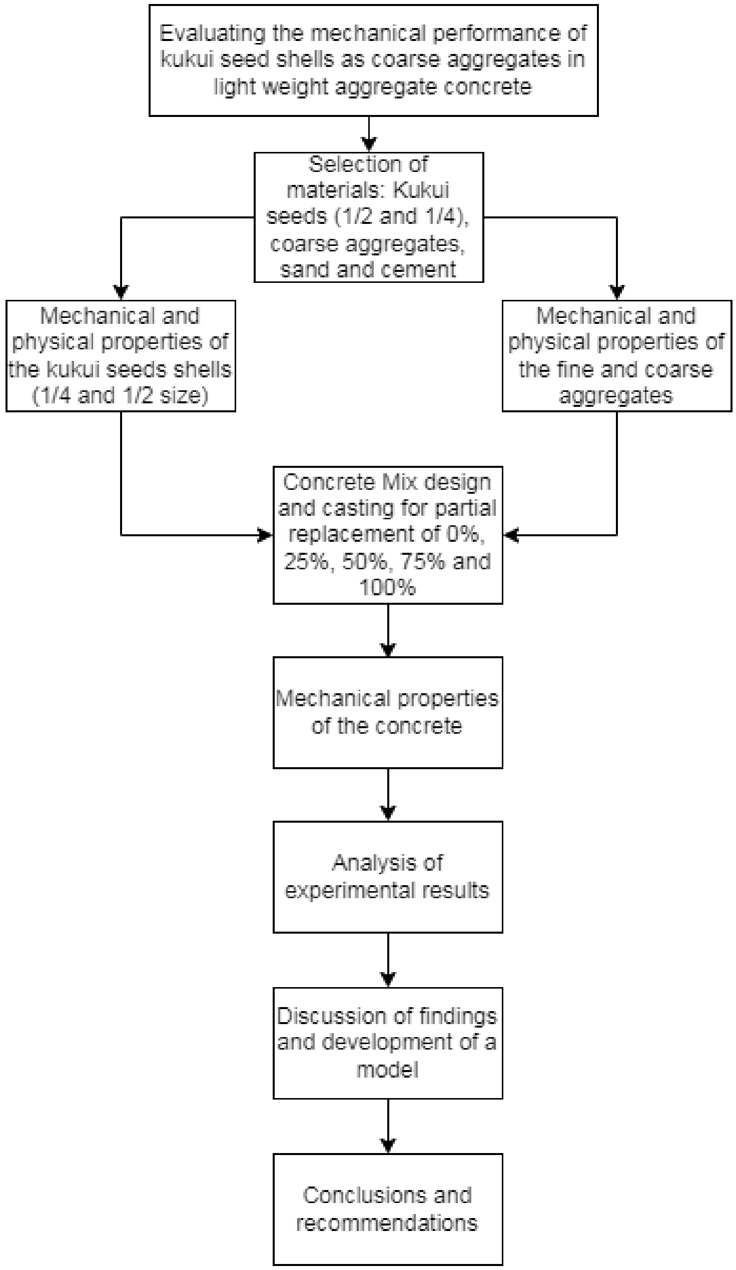


Figure 3- 1: Flow chart showing the research methodology

3.1.2 Research Approach

3.1.2.1 Sample coding

To ease identification throughout the research process, the concrete samples were assigned a unique identification code typical of the sample partial replacement percentage, the seed size and the test which was going to be carried out on the sample. The **Table 3-1** below summarizes the sample codes that were assigned to the samples during the test.

Table 3- 1: Sample coding guide

No.	**Material Test**	**Sample**		
		Coarse Aggregates	**Quarter Seed Shell**	**Half Seed Shell**
1	Compressive strength	CS/CA/"no."	CS/QSS/ "% partial replacement" / "no."	CS/HSS/ "% partial replacement" / "no."
2	Flexural strength	FS/CA/"no."	FS/QSS/ "% partial replacement" / "no."	FS/HSS/ "% partial replacement" / "no."
3	Splitting Tensile Strength	ST/CA/"no."	ST/QSS/ "% partial replacement" / "no."	ST/HSS/ "% partial replacement" / "no."
4	Water Absorption	WA/CA/"no."	WA/QSS/ "% partial replacement" / "no."	WA/HSS/ "% partial replacement" / "no."
5	Modulus of Elasticity	ME/CA/"no."	ME/QSS/ "% partial replacement" / "no."	ME/HSS/ "% partial replacement" / "no."
6	Thermal Conductivity	TC/CA/"no."	TC/QSS/ "% partial replacement" / "no."	TC/HSS/ "% partial replacement" / "no."
7	Xray test	X/CA/"no."	X/QSS/ "% partial replacement" / "no."	X/HSS/ "% partial replacement" / "no."
8	Fire resistance test	FR/CA/"no."	FR/QSS/ "% partial replacement" / "no."	FR/HSS/ "% partial replacement" / "no."

Legend

- The "no." represents the number of the cube or beam or cylinder. For example, if there are 4 cubes that need a compressive strength test and they have coarse aggregates only, the codes will be "CS/CA/01, CS/CA/02, CS/CA/03, CS/CA/04"
- The "% partial replacement" represents the percentage of the seeds that are within the mix. For example, if there are 4 cubes that have used 75% of the QSS seeds needed for Thermal Conductivity test, the codes will be "TC/QSS/75/01, TC/QSS/75/02, TC/QSS/75/03 TC/QSS/75/04"

3.1.2.2 Material Properties

The materials to be used are; kukui seed shells (Half and Quarter Seed Shells), Coarse Aggregates, Fine Aggregates and Cement

i. Kukui seed shells

a. Identification of the source of the Kukui seed shells

The kukui seed shells were obtained from Rushogashoga village, Sheema district (-0.621414, 30.371181) in Western Uganda. It is 300km away from Kampala. A group of farmers ventured into planting the kukui tree so as to tap into the various advantages this tree has. The farm where the samples were collected, has more than 100 kukui trees producing more than 8 tonnes of seeds in a season. Quarter and Half Seed Shells were collected for the experiments. The shells extracted were a residue of the crushing process for extraction of kukui oil.

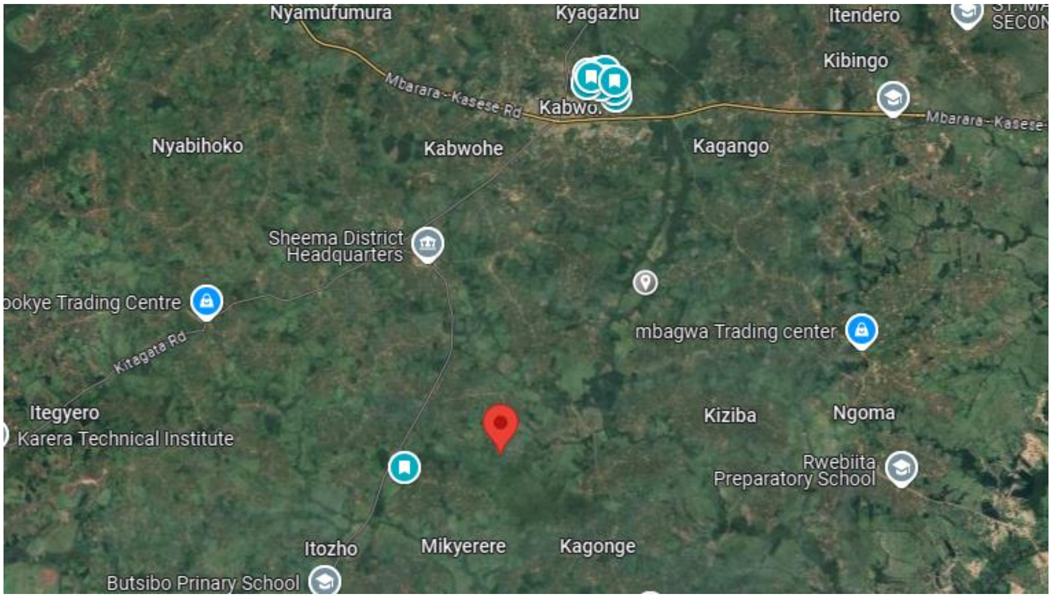


Figure 3- 2: Location of the source of materials

a

c. *Material Extraction and Preparation process*

In order to extract the oil from the kukui seed, the shells are broken in order to access seed which has the oil. Since the shell is hard, a crushing machine is used. The machine that crushes these seeds was manufactured in Katwe (Kampala) with specifications from its user. It has a 5mm thick bar bent into a crushing member. This system is attached to a 3KW mortar that rotates the pulley at 2800rpm. When the seeds are crushed, they pass through a sieve of 25mm size. With the help of the locals, the author sorted the residue shells in the Quarter and Half seed shell sizes that were needed. It was observed that approximately 56% of the seeds were an Eighth (1/8) seed shell, 34% were Quarter (¼) seed shell and 10% were Half (½) seed shells. During sieve analysis, majority of the Eighth (1/8) seed shells passed through the 5mm sieve which placed under the criteria of "fine aggregates" which isn't covered under the author's scope.

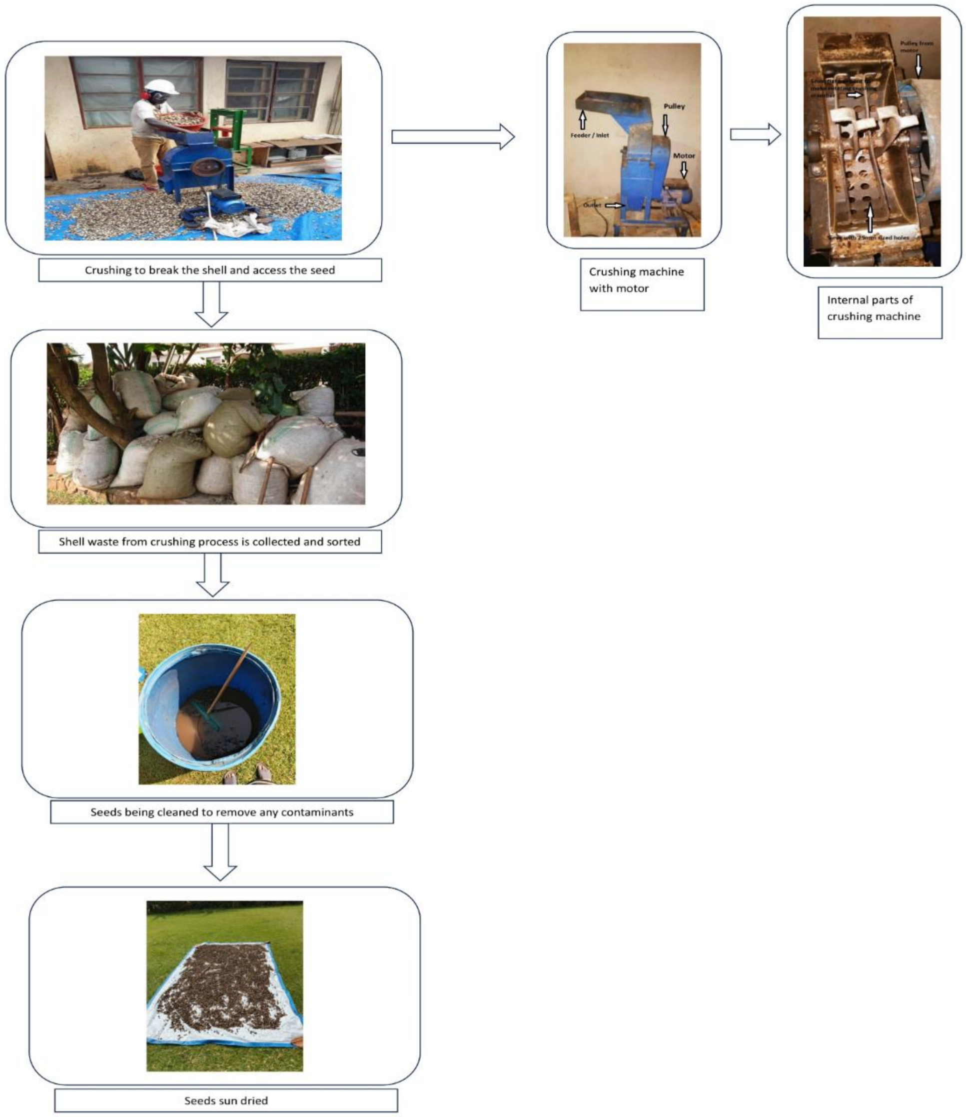


Figure 3- 3: Extraction and preparation process

ii. Cement

CEM II (32.5N) - Portland Pozzolana Cement (PPC) manufactured by Tororo Cement was used.

iii. Aggregates

Aggregate size of 20mm (maximum) were used. The coarse aggregates were acquired from Muyenga and fine aggregates from Lwera.

iv. Water

Ordinary Portable water was used.

3.1.2.3 Material tests

Material Test Program

Table 3-2 below shows the material tests, objectives and significance of carrying out the tests, the apparatus usually used to carry out the tests and the threshold for each test result. It was used as a guideline for the material tests that were carried out on the kukui seeds and concrete sample.

Table 3- 2: Material test program

No.	Material Test	Objective and Significance	Apparatus	Expected results
1	Partical size distribution: Sieve Analysis for Fine aggregates, Coarse Aggregates and the kukui seed shell samples (Half and Quarter Seed Shell)	To determine the particle size distribution of aggregates which would affect the quality and performance of the concrete.	Test sieves (diameter 450mm to 75 µm), weighing scale, A drying oven, Riffle boxes, Metal container, Sieve brushes	The material should be fit to be used in concrete. Refer to Table 3 in BS812.
2	Flakiness Index of Coarse Aggregates and the kukui seed shell samples (Half and Quarter Seed Shell) (Half and Quarter Seed Shell)	To determine the percentage of flaky particals in the aggregates. Flaky particals usually leads to weaker concrete which breaks easily on heavy impact.	Test sieves for both partical distribution and flakiness (diameter 450mm to 75 µm), weighing scale, A drying oven, Riffle boxes, Metal container, Sieve brushes	The flakiness Index of the aggregates shall not exceed 40%. (BS812)
3	Aggregate Impact Value (AIV)	This is a test to check a materials ability to resist impact loads. The lower the AIV value, the more resistant the material. The impact value is derived from the percentage of fines collected after the AIV test.	Aggregate Impact Testing machine, Test sieves (14 mm and 10 mm and 2.36 mm sieve), Tamping rod (steel bar 16mm diameter and 600 mm long), A riffle box, Oven (105 ± 0.5°C), Brush with Stiff bristles, weighing scale	AIV is expected to be less than 25%. (BS812)
4	Aggregate Crushing Value (ACV)	This is a test to check a materials ability to resist crushing loads. The lower the ACV value, the more resistant the material.	Compression machine, Test sieves (14 mm and 10 mm and 2.36 mm sieve), Tamping rod (steel bar 16mm diameter and 600 mm long), A riffle box, Oven, Brush with Stiff bristles, Weighing scale	ACV is expected to be less than 30% (BS 812-110)
5	Density and water absorption of the coarse aggregates and kukui seed shells	These are both used in calculations for the concrete mix designs to determine the weights required for each material and the water needed	Oven (105 ± 0.5°C). weighing scale, glass vessel with water tight cover (1.0 liter to 1.5 liters' capacity)	For the Light Weight Aggregates, density should be below 2000 kg/m3. Water absorption shall not be less than 4 % (BS 8007)

		for the mix.		
6	Los Angeles Abrasion Test (LAA)	A method used to measure the resistance of aggregates to abrasion.	LAA Abrasion machine, Abrasive steel balls, sieves, weighing scales	30% (AASHTO)
7	Soundness	The ability of an aggregate to resist deterioration from weathering processes, particularly freeze-thaw cycles and wet-dry cycles	Sodium Sulphate, , Oven (105 ± 0.5°C), weighing scales, glass vessel with water tight cover (1.0 liter to 1.5 liters' capacity)	Less than 6% (BS882)
8	Silt Content	The maximum silt content recommended for fine aggregates	1% salt solution, 200ml graduated cylinder	Less than 4% (BS882)
8	Compressive strength	The ability of the concrete to resist crushing (150mm x 150mm x 150mm concrete cubes used)	Compression machine, weighing scale	25MPa
9	Flexural Strength	The ability of the beam to resist bending. A 150mm x150mm x 750mm beam was used.	Flexural machine, weighing scale	2.6MPa (EN1992)
10	Split Tensile Strength	The ability of the concrete to resist splitting. A cylinder of 100mm diameter and 200mm length was used.	Compression machine, weighing scale	2.2MPa (EN1994)
11	Modulus of Elasticity	The stress-strain relationship of the concrete	Compression machine, deformation measuring apparatus	As per Eurocode 2-1-1, for C20/25 concrete it should be 29,962MPa
12	Water Absorption	The percentage of water that the concrete absorbs.	Oven (105 ± 0.5°C), water bath	Less than 3% (BS 6349)
13	Thermal Conductivity	The ability of a material to resist or allow transfer of heat through the material. A 100mm long, 50mm	Thermal Conductivity machine	0.51W/mK – 1.33W/mK (BS EN 1745)

		wide and 25mm thick sample of the concrete is placed in the Thermal Conductivity machine. The machine passes heat through the sample and a temperature gradient is obtained. The machine measures how fast the heat moves through the sample and provides a value. This value is its thermal conductivity in Watts per mter Kelvin (W/mK).		
14	Fire resistance	Ability of a material to resist fire and its heat and remain within the parameters of specifications	Kiln, Compression machine	Compressive strength should be constant until 500°C (BS8110-2:1985)
15	Morphology, internal topography and element composition	This test draws more light on the characteristics of the hardened concrete and the kukui seed shells	Digital Xray machine and Scanning Electron Microscope (SEM)	Not Applicable

Material test procedure

The **Tables 3-3**, **3-4** and **3-5** below show a summary of the tests, specifications, number of specimens to be used and tests to be carried out on the materials in order to achieve the author's specific objectives.

Table 3- 3: Kukui seed shell and coarse aggregate mechanical test details

No.	Test	Reference	Samples	Comment
Tests on the kukui seed shells				
1	Aggregate Crushing Value	BS812:Part 110:1990	2 samples	Half and Quarter seed shells were tested.
2	Water Absorption	BS812:Part 109:1990	2 samples	
3	Sieve Tests	BS812: Part 2:1975	2 samples	
4	Flakiness Test (FI)	BS812: Section 105.1:1989	2 samples	
5	Aggregate Impact Value	BS812:Part 112:1990	2 samples	
6	Los Angeles Abrasion Test (LAA)	ASTM C535-89	2 samples	
7	Soundness	ASTMC 88-90	2 samples	
8	Morphology, internal topography and element composition	ASTM E986-04:2017	1 sample	
Tests on the Aggregates				
1	Water Absorption	BS812:Part 109:1990	2 samples	This test was carried out on both the fine and coarse aggregates.
2	Sieve Tests	BS812: Part 2:1975	2 samples	
3	Flakiness Test (FI)	BS12: Section 105.1:1989	1 sample	This test was carried out on the coarse aggregates.
4	Aggregate Crushing Value	BS812:Part 110:1990	1 sample	
5	Aggregate Impact Value	BS812:Part 112:1990	1 sample	
6	Los Angeles Abrasion Test (LAA)	ASTM C535-89	1 sample	
7	Silt Content	AASHTO T 11	1 sample	This test was carried out on the fine aggregates

Table 3- 4: Hardened concrete mechanical testing details

No.	Test	Reference	Samples	Comment	Kukui seed shells (Composition by%) for Half and Quarter seed shell sizes				
					0	**25**	**50**	**75**	**100**
1	Compressive Strength	BS 1881-116:1983	54	3 samples for 7 days and 28 day maturity	√	√	√	√	√
2	Flexural Strength	BS EN12390-5	27	3 samples for 28 day maturity	√	√	√	√	√
3	Modulus of Elasticity	BS 1881-Part 121-83	27	3 samples for 28 day maturity	√	√	√	√	√
4	Splitting Tensile Strength	BS EN12390-5	27	3 samples for 28 day maturity	√	√	√	√	√

Table 3- 5: Concrete mechanical testing details

No.	Test	Reference	Samples	Comment	Kukui seed shells (Composition by%) for Half and Quarter seed shell sizes				
					0	**25**	**50**	**75**	**100**
1	Thermal conductivity	BS EN 1745	27	3 samples for 28 day maturity	√	√	√	√	√
2	Fire resistance	*EN 13381-3:2015*	18	2 samples for 28 day maturity	√	√	√	√	√
3	Water Absorption	*BS 1881-122:2011+A1:2020*	27	3 samples for 28 day maturity	√	√	√	√	√
4	Internal topography of the concrete cube (Digital X-ray machine)	*ASTM F792*	27	3 samples for 28 day maturity	√	√	√	√	√

3.1.2.4 Structural element simulation (Finite Element Analysis)

Introduction

A beam is a horizontal structural element that sustains shear forces and bending moments when loads acting perpendicular to the longitudinal axis are applied to it (Hibbeler, 2023). Due to these loads, a beam deflects depending on the type and position of the load acting on it. The capacity of a structure to continue operating under anticipated load circumstances while staying within allowable bounds for deflection, vibration, and cracking is known as serviceability (Hibbeler, 2023). The author will explore the serviceability capability of the beam in terms on "deflection".

The author has eight beams to simulate. In this methodology, the author will use the properties of the control concrete (100%CA) to explain his simulation methodology. In chapter four: results and discussions, the different material properties were adjusted accordingly depending on the partial replacement percentages.

The **Figure 3-4** below shows the fixed ended beam with a point load acting midspan. This structural element condition will be used in this research. **Figure 3-5** shows a summary of the simulation process that was used.

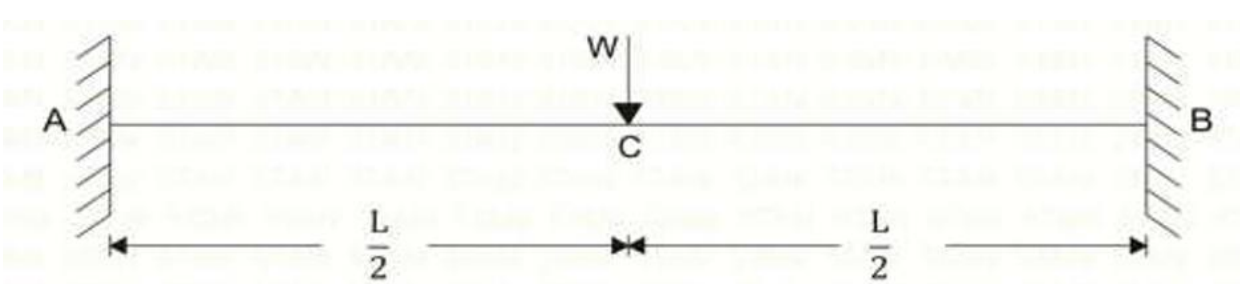


Figure 3- 4: Illustration of fixed ended beam considered

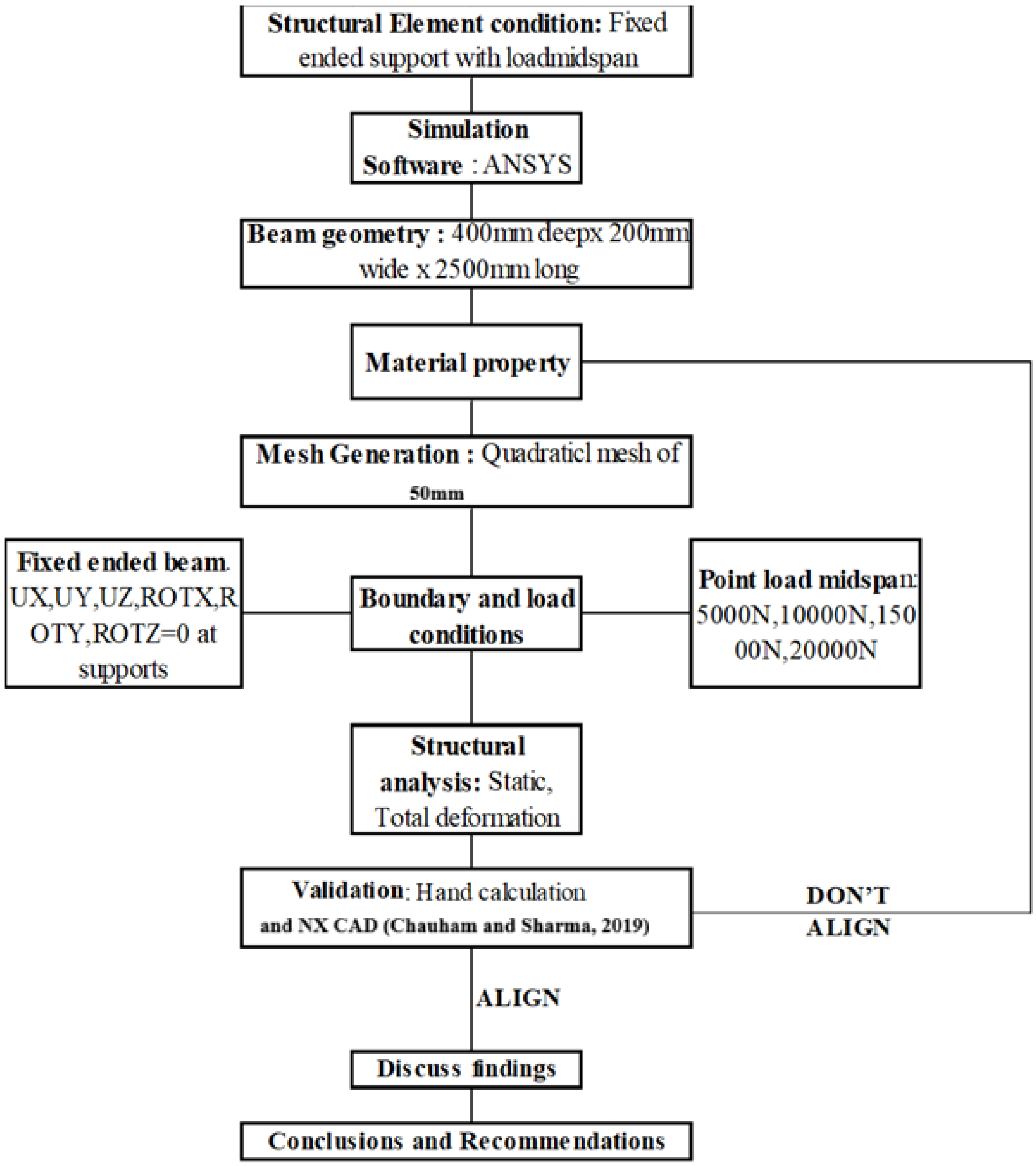


Figure 3- 5: Simulation process

Simulation Software

Beam modelling and structural analysis was done in "***ANSYS Workbench 2025 R1***". ANSYS was used because it is a widely accepted software for engineering simulations and design. The analysis type is “Static Structural Analysis”. Under this analysis type of analysis no dynamic or lateral loads were assumed.

Material properties

Concrete was used as a material because 60%of sites use it as a building material (Aytekin et al, 2022). After the experimental analysis of the effects of the different partial replacements of the kukui seed shells on the mechanical properties of concrete, the extracted mechanical properties were used in ANSYS during simulation. The mechanical properties are shared in **Table 4-10**.

Beam geometry

The geometric specification of the beam was a 400mm high, 200mm wide and 2500mm long beam. The minimum span to depth ratio in recommended in Eurocode 2 is 20. The beam used is 2500mm in length, so the minimum depth of the beam for that span was 125mm hence the use of a beam with 400mm depth. It was modelled under “Design Modular”.

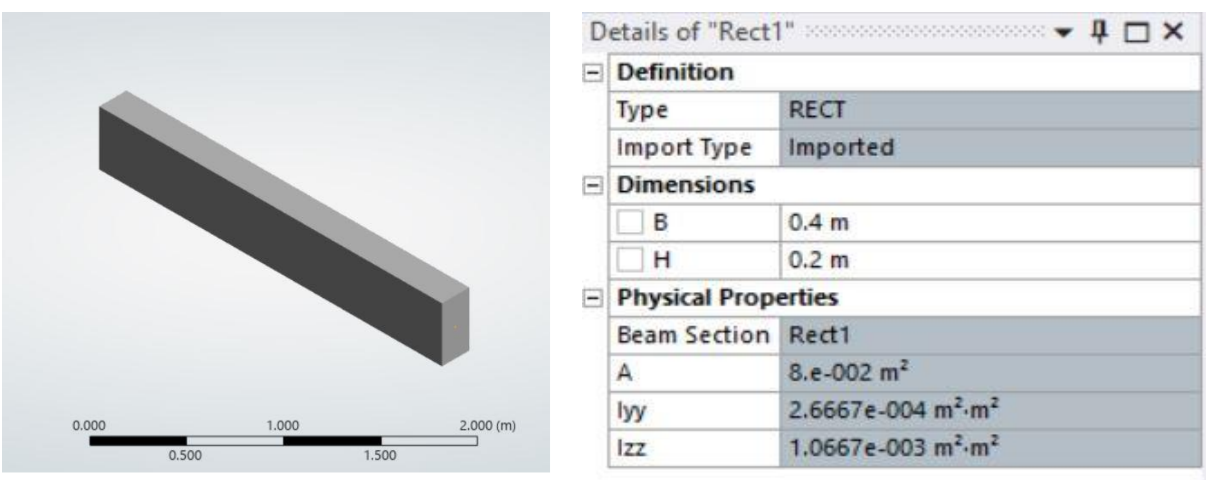


Figure 3- 6: Illustration of beam geometry

Mesh Generation

Meshing is the discretization of a structure into finite elements (Cook, 2001). The beam was meshed using quadratic structured mesh of 50mm size.

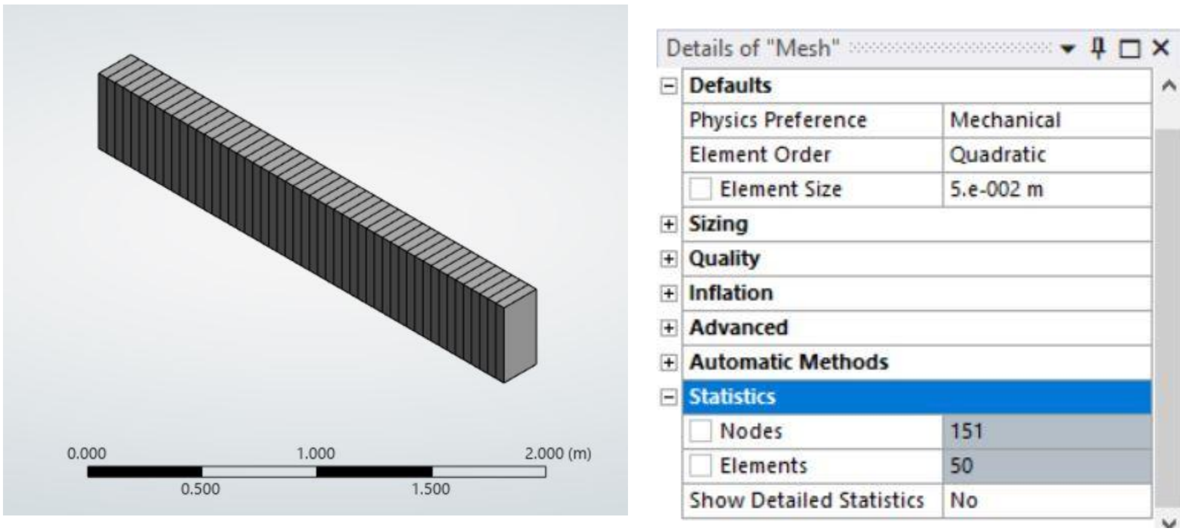


Figure 3- 7: Illustration of meshing pattern

Boundary and loading conditions

A fixed ended beam was envisioned (Fixed at **A** and **B**). Point loads (**W**) of 5000KN, 10,000KN, 15,000KN and 20,000KN were applied midspan (at **C**) in the negative y direction (gravity load) as shown in **Fig 3-8** below. (At x=0 and x=2.5m; UX=0, UY=0, UZ=0, ROTX=0, ROTY=0, ROTZ=0)

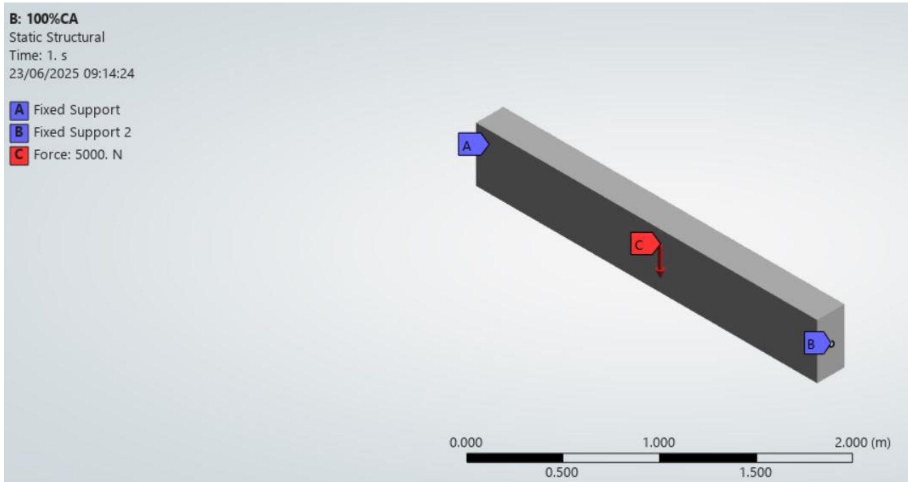


Figure 3- 8: Illustration of boundary and loading conditions

Structural analysis

The simulation was run to determine the total deformation of the beam along its span. The readings for midspan deformation were recorded for each of the point loads applied and presented in a graph.

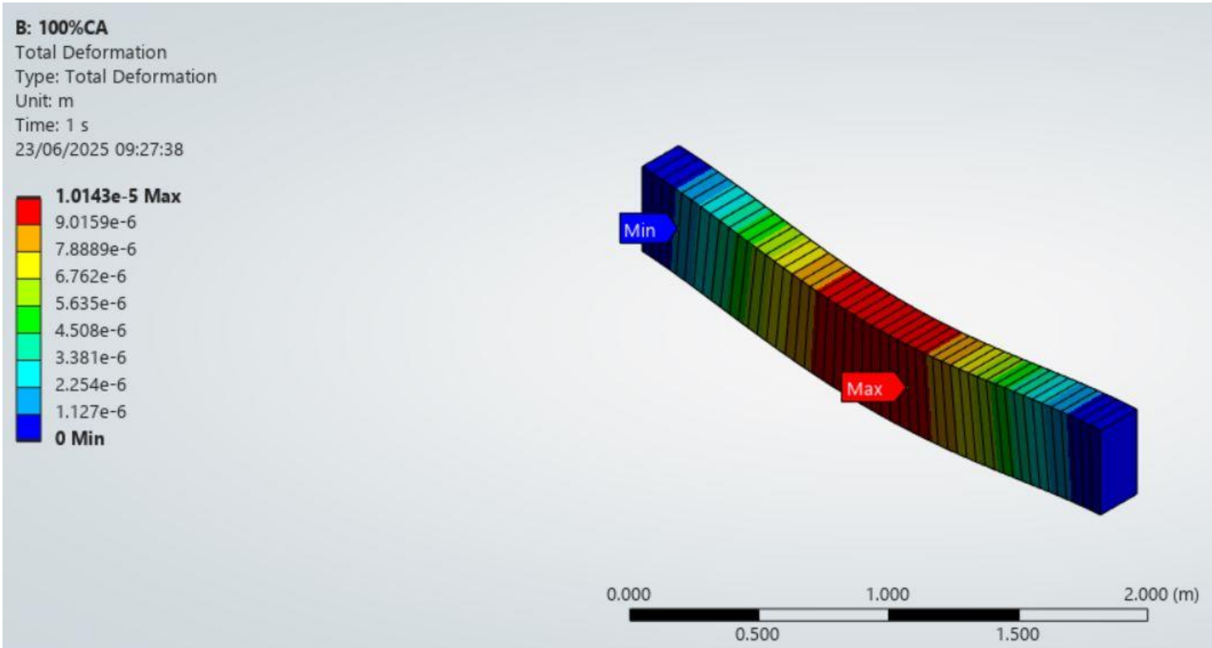


Figure 3- 9: Illustration of one of the outputs from the analysis

Validation

Under "Analysis of different Beams" (Chauham and Sharma, 2019), the authors undertook a statical analysis of a beam with a rectangular cross section under different loading conditions. These conditions included point load (midspan) and uniformly distributed loading. The beams in the analysis had generalized support conditions i.e. simply supported, cantilevered and fixed support conditions. The Finite Element Analysis was done using NX Cad. The aim of the author's study was to compare the deflection values from hand calculations (using Euler-bernoulli's beam equation) to the output from NX Cad. Validation of the work in my study encompassed comparing his hand calculations and NX Cad output from his simulation with the output from my ANSYS simulation. A fixed ended beam with a point load midspan was taken into consideration.

Material properties

The properties of the beam using during validation are shown in the **Figure 3-10** below:

castiron

Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	1.31e+11 Pa
Poisson's Ratio	0.25
Bulk Modulus	8.7333e+10 Pa
Shear Modulus	5.24e+10 Pa
Tensile Yield Strength	1.3e+08 Pa

Figure 3- 10: Material properties used in the ANSYS software (Chauham and Sharma, 2019)

Beam geometry

In their study, they used a beam with the parameters shown in **Fig. 3-11** below:

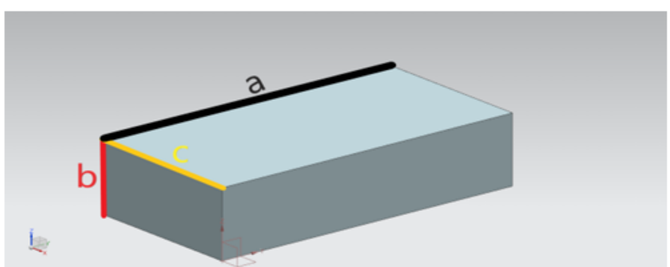


Figure 3- 11: Beam dimensions used in the research (Chauham and Sharma, 2019)

From **Fig. 3-11**, the height of the beam (b) was 50mm, the width of the beam (c) was 100mm and the length of the beam (a) was 200mm.

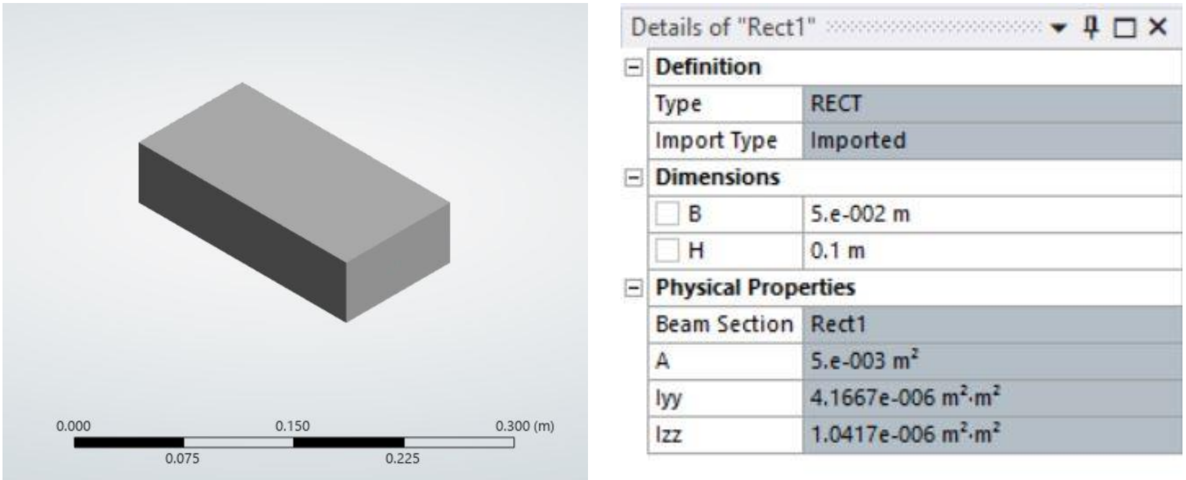


Figure 3- 12: Illustration of beam geometry in program

Mesh Generation

The beam was meshed using quadratic structured mesh of 10mm size.

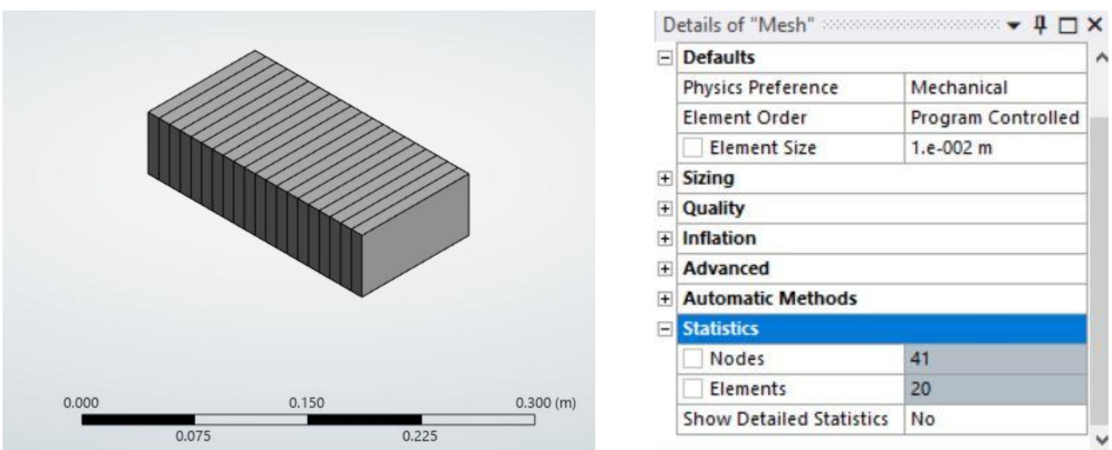


Figure 3- 13: Illustration of meshing pattern

Boundary and loading conditions

A fixed ended beam was envisioned (Fixed at **A** and **B**). Point loads (**W**) of 5000KN was applied midspan in the negative y direction (gravity load) as shown in **Fig. 13** below. (At x=0 and x=0.2m; UX=0, UY=0, UZ=0, ROTX=0, ROTY=0, ROTZ=0)

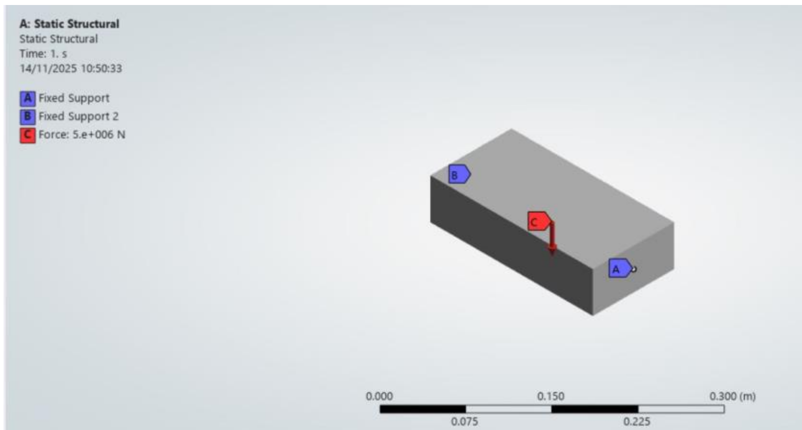


Figure 3- 14: Illustration of boundary and loading conditions

Structural analysis

The simulation was run to determine the total deformation of the beam along its span. The readings for midspan deformation were recorded and compared with what was discovered in the study. **Figure 3-15** below shows the output from the ANSYS analysis.

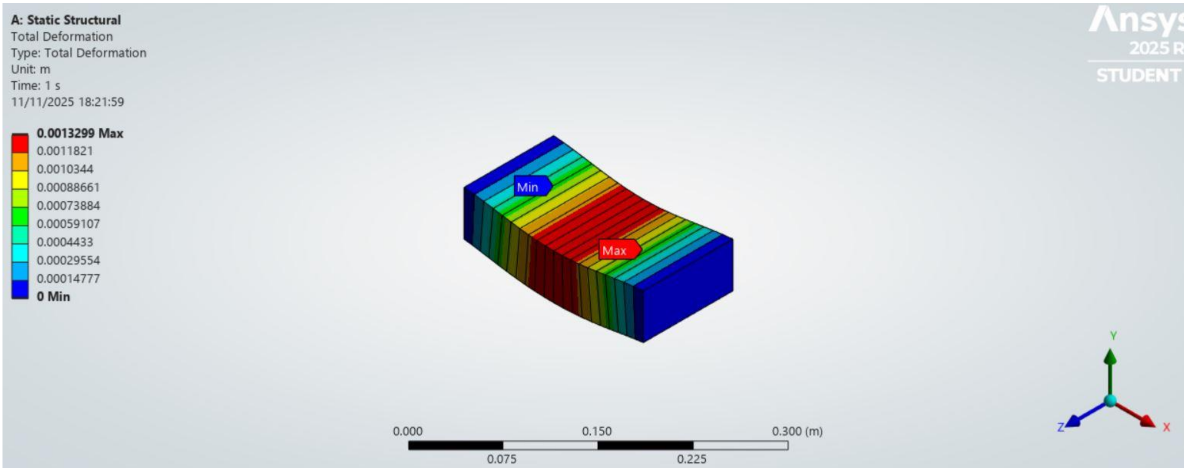


Figure 3- 15: Deflection output from ANSYS

Furthermore, **Table 3- 6** shows the deflections derived from the analysis.

Table 3- 6: Different statistics from deflection output

No.	Analysis type	Source	Deflection (mm)	Absolute Error (ANSYS-Hand/NX) (mm)	Percentage error (%)	Mean (mm)	Standard deviation (mm)	Confidence interval of 95%	Margin of error (mm)
1	Hand Calculation	Chauham and Sharma, 2019	1.904	0.5741	30%	1.631	0.386	0.535	1.631 +/- 0.535
2	NX CAD		1.358	0.0281	2%				
3	ANSYS	Author	1.3299						

The output from ANSYS lies within the error margin of error which is 1.631 ± 0.535 and has a low percentage error of 2% in relation to NX CAD. Therefore, ANSYS provides sufficiently accurate predictions for analysis of deflection.

3.1.2.5 Discussion of findings

The different deformations for the different partial replacement beam simulations were shared and results discussed. On analysis of the results, the maximum deflection was derived and the load that all the samples reach this maximum deflection was tabulated. From EN 1992, the maximum deflection is gotten by:

$$Maximum_{deflection} = \frac{Member\ length}{250} = \frac{2500}{250} = 10mm$$

Therefore, the maximum deflection was calculated to be 10mm. From this, appropriate discussions were derived.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

The results for the tests conducted for this research, their analysis and discussions are recorded in the chapter. They will be discussed in reference to the different specific objectives of this report. A total of 210 cubes, 30 cylinders and 30 Beams were cast. An appropriate mix design was adopted to achieve C25 concrete. Partial replacements of the Quarter Size Shell (QSS) and Half Size Shell (HSS) with respective coarse aggregates was done in percentages of 0%, 25%, 50%, 75% and 100%. Data from the physical, mechanical tests, water absorption and thermal conductivity performance of the concrete was presented using bar graphs with error bars.

The detailed breakdown of how the mechanical tests were carried out are shared in **Appendix A.3** and pictures of the author carrying out the tests in **Appendix A.4.**

4.2 Presentation and Analysis of Results

A. Specific Objective 1: To determine the mechanical properties, physical properties and sizes of kukui seed shells to be used in concrete

4.2.1 General measurements of the seed shells

Fig. 4-1 and **Fig. 4-2** below show different dimensions and elevations of the seed shells that were used in the different tests that were carried out.

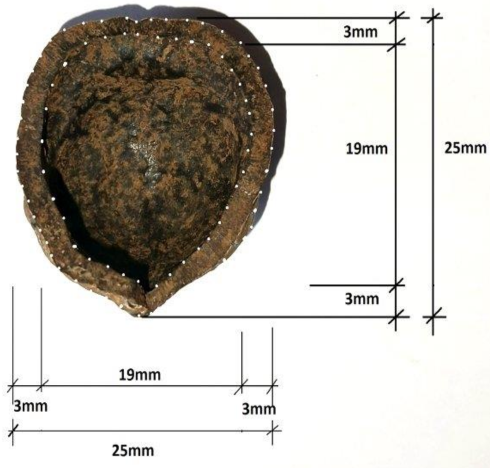
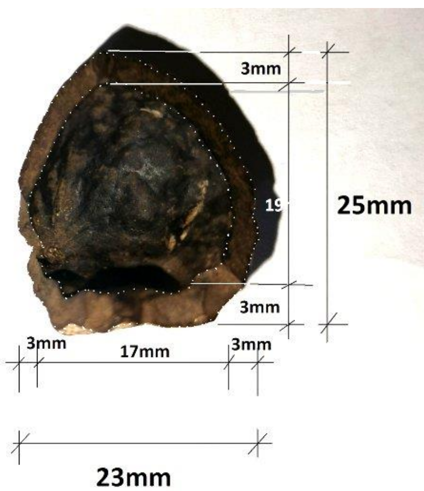


Figure 4- 1: Dimensions of Half seed shell



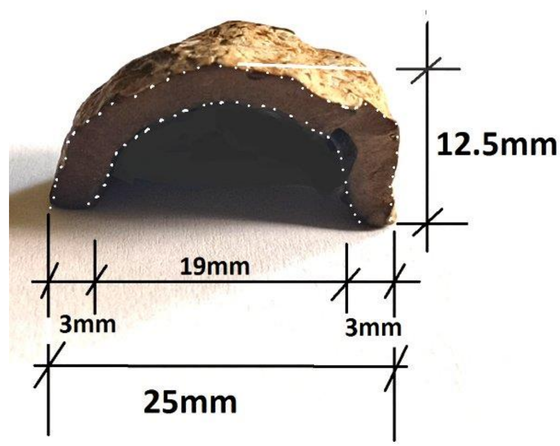
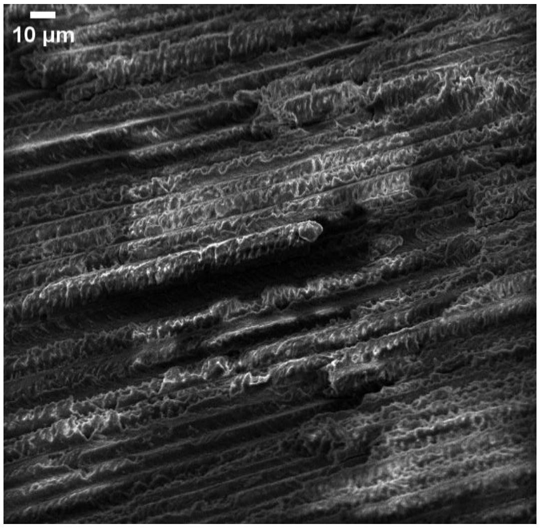


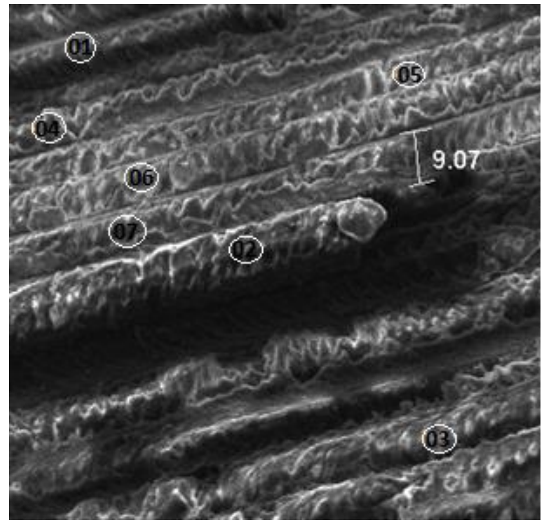
Figure 4- 2: Dimensions of Quarter Seed Shell

4.2.2 Morphology, internal topography and element composition

The Scanning Electron Microscope (SEM) was used to magnify the kukui seed shells and determine its chemical composition. The output of this magnification was shared and it was determined that the longitudinal grains are arranged in thin layers connected parallel to one another. This means that the seeds are anisotropic. Due to this, the mechanical properties of the seed shell parallel to the grains and those perpendicular to the grains are different. **Figure 4-3** shows the different outputs from the SEM.



Arrangement of layers



Thickness of layers

Figure 4- 3: Kukui Seed Shell microstructure

The **Table 4-1** Below shows the different thicknesses of the layers of the Kukui Seed Shells:

Table 4- 1: Kukui Seed Shell layer thickness

Label	Thickness (micro meters)
1	10.728
2	9.485
3	8.944
4	6.069
5	8.521
6	9.951
7	9.07
8	9.924
Mean	9.087
Min	6.069
Max	10.728

The **Table 4-2** below shows the different chemical compositions of the tested kukui seed shell

Table 4- 2: Chemical Composition of Kukui Seed Shells

No.	Chemical	Kukui shell Sample-1	Kukui shell Sample-2	Average
1.	Oxygen (O)	92.9	86.1	89.5
2.	Calcium (Ca)	2.2	7.5	4.9
3.	Aluminum (Al)	1.01	3.0	2.0
4.	Sulfur (S)		2.0	1.0
5.	Silicon (Si)	0.8	1.4	1.1
6.	Carbon (C)	0.1	0.1	0.1
7.	Potassium (K)	1.8		0.9
8.	Sodium (Na)	1.2		0.6

The high chemical composition of oxygen in the shell reflects a presence of Lignin and Cellulose (Zhou et al., 2010). This affirms the natural composition test results carried out by "Kafama,2020" on the seeds shared in **Table 2-2** in the author's Literature Review.

4.2.3 Mechanical properties of aggregates (kukui seed shells, fine aggregates and coarse aggregates)

Tests were carried out on the Half seed shells (HSS), Quarter Seed Shells (QSS), coarse aggregates and fine aggregates. Below are the different results derived from carrying out the tests:

Grading (Sieve Analysis)

Sieve analysis was done on four samples ie Half Seed Shells (HSS), Quarter Seed Shells (QSS), Coarse Aggregates and Fine Aggregates. **Figure 4-3** below shows the grading of fine aggregates used during the partial replacement mixing:

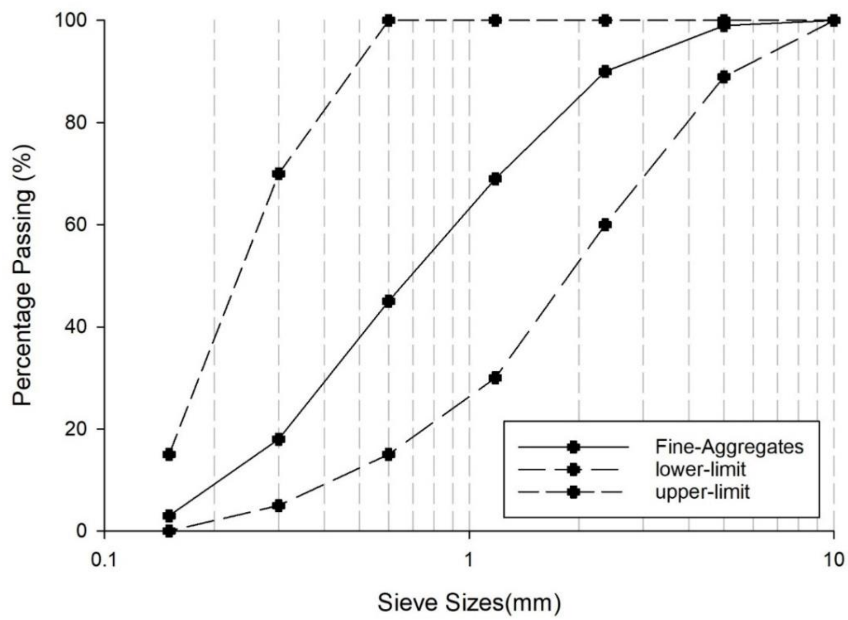


Figure 4- 4: Fine Aggregate grading curve

Table 4-3 below shows the parameters for Coefficient of Uniformity and Coefficient of Curvature for the fine aggregate sample

Table 4- 3: Parameters for Coefficient of Uniformity and Coefficient of Curvature for the fine aggregate sample

No.	Parameter	Value	Comment
1	Coefficient of Uniformity (C_u)	4.50	Uniformly graded
2	Coefficient of Curvature (C_c)	1.03	Well graded

The fine aggregates are uniformly graded. In reference to BS822:1992: Table 4, the fall within the grading limits to be used for heavy duty concrete floor finishes therefore it can be used in the concrete.

Sieve Analysis was also carried out on the Half Seed Shells (HSS) and Quarter Seed Shells (QSS). Figures **4-4** and **4-5** show the grading of the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) respectively.

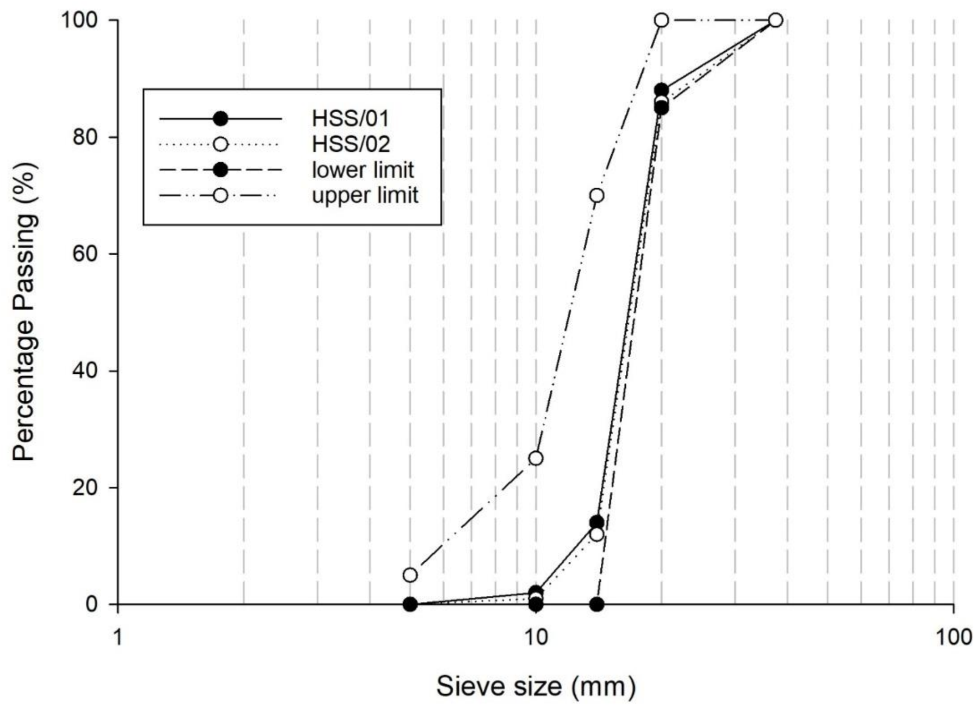


Figure 4- 5: Half Seed Shell (HSS) grading curve

Table 4-4 below shows the parameters for Coefficient of Uniformity and Coefficient of Curvature for the Half Seed Shell sample

Table 4- 4: Parameters for Coefficient of Uniformity and Coefficient of Curvature for the Half Seed Shell sample

No.	Parameter	Average Value	Comment
1	Coefficient of Uniformity (C_u)	1.30	Uniformly graded
2	Coefficient of Curvature (C_c)	1.09	Well graded

The Half Seed Shells (HSS) are uniformly graded. They have a maximum particle size of 20mm. In reference to "BS822:1992, Table 3", the shells are categorized as "20mm single sized aggregates".

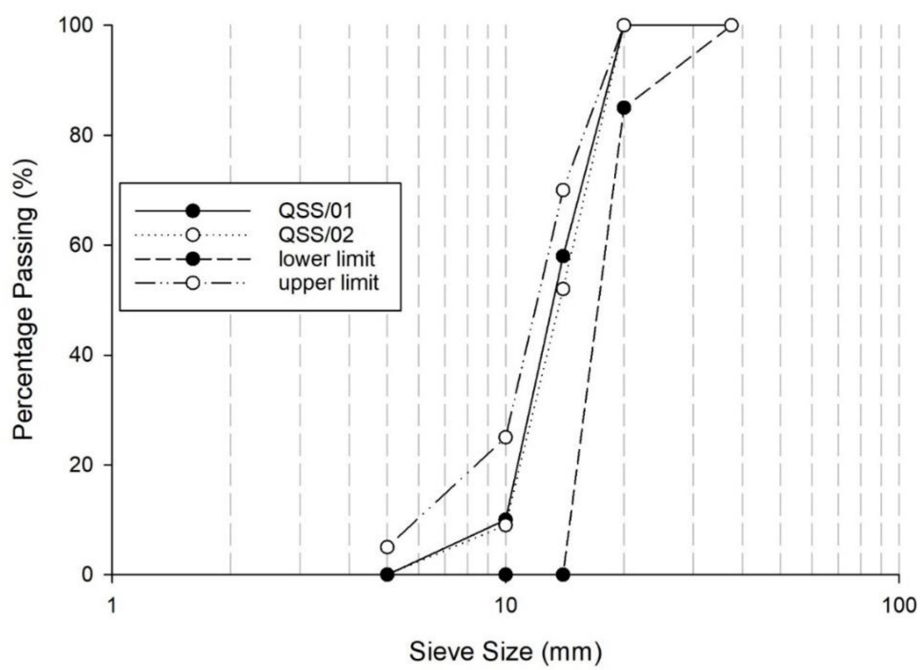


Figure 4- 6: Quarter Seed Shell (QSS) grading curve

Table 4-5 below shows the parameters for Coefficient of Uniformity and Coefficient of Curvature for the Quarter Seed Shell (QSS) sample

Table 4- 5: Coefficient of Uniformity and Coefficient of Curvature for the Quarter Seed Shell (QSS) sample

No.	Parameter	Average Value	Comment
1	Coefficient of Uniformity (C_u)	1.46	Uniformly graded
2	Coefficient of Curvature (C_c)	0.96	Uniformly graded

The Quarter Seed Shells are uniformly graded. They have a maximum particle size of 14mm. In reference to "BS822:1992, Table 3", the shells are categorized as "20mm single sized aggregates".

An appropriate coarse aggregate was necessary as it would be used as our control material for the partial replacement process. The selected coarse aggregates had similar grading to the kukui seed shells (both Quarter and Half Seed Shells). **Figure 4-7** shows the grading of the coarse aggregate sample that was chosen for the partial replacement assignment:

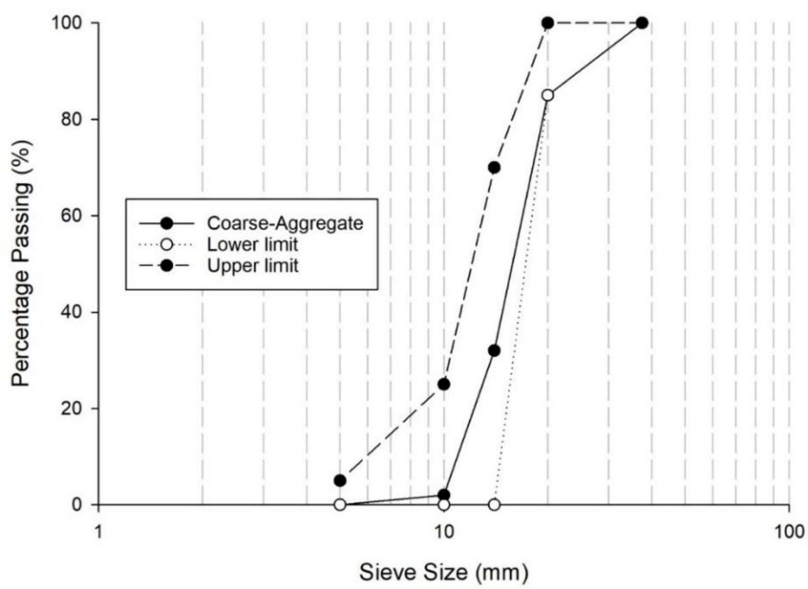


Figure 4- 7: Coarse Aggregate grading curve

Table 4-6 below shows the parameters for Coefficient of Uniformity and Coefficient of Curvature for the Coarse Aggregate (control material) sample

Table 4- 6: Coefficient of Uniformity and Coefficient of Curvature for the selected Coarse Aggregate (control material) sample

No.	Parameter	Average Value	Comment
1	Coefficient of Uniformity (C_u)	1.41	Uniformly graded
2	Coefficient of Curvature (C_c)	0.96	Uniformly graded

The Coarse Aggregates are uniformly graded. They have a maximum particle size of 20mm. In reference to "BS822:1992, Table 3", the aggregates are also categorized as "20mm single sized aggregates". The **Table 4-7** below shows a summary of Mechanical properties of kukui seed shells, fine aggregates and coarse aggregates

Table 4- 7: Mechanical properties of kukui seed shells, fine aggregates and coarse aggregates

No.	Material Property	Aggregate Type				
		Coarse Aggregates	Fine Aggregates	Half Seed Shells	Quarter Seed Shells	Standard
1.	Specific Gravity	2.637	2.598	1.421	1.394	N/A
2.	Density (kg/m^3)	2,637	2,598	1,421	1,394	2000
3.	Water Absorption (%)	0.233	2.438	14.02	14.36	3
4.	Flakiness Index (%)	32.5		95.3	60.3	40
5.	Aggregate Impact Value (%)	26.5		9.0	10.7	25
6.	Aggregate Crushing Value (%)	22.2		15.2	14.1	30
7.	Los Angeles Abrasion Value (%)			16.7	17.6	30
7.	Soundness	0.43		1.14	4.12	6
8.	Silt Content		3			4

Density

The Half Seed Shells (HSS) and Quarter Seed Shells (QSS) all fall under the category of "Light Weight Aggregates" since their density is below 2000kg/$m3$ (EN 1992-1-1:2004).

Water Absorption

The Half Seed Shells (HSS) and Quarter Seed Shells (QSS) have high water absorption percentages. This is due to the lignin and cellulose found in the shell. Though those chemicals are hydrophobic, they act like a sponge and retain any water that might have entered any pores that the shell has (Zhang et al., 1996)

Flakiness Index

The Half Seed Shells (HSS) and Quarter Seed Shells (QSS) have high fakiness index percentages. This is probably due to the crusher used. Although impact crushers produce less flaky aggregates, when the aggregates have a hard shell, the motor rotation speed should be optimized in order to reduce the flaky aggregates (Gupta and Yan, 2016). A higher rotational motor speed is recommended for better aggregate output.

Aggregate Impact Value (AIV)

The Half Seed Shells (HSS) and Quarter Seed Shells (QSS) are within the recommended specifications limits. The presence of lignin and cellulose in the seed shell contributes to the shell's rigidity and strength (Dai, Chen and Wei, 2023) this improves its performance when loaded and leads to lower AIV values.

Aggregate Crushing Value

All the tested aggregates (Half Seed Shell, Quarter Seed Shells and Coarse Aggregates) are within the recommended specification limits. The presence of lignin and cellulose in the seed shell contributes to the shell's rigidity and strength (Dai, Chen and Wei, 2023) this improves its performance when loaded and leads to lower ACV values.

Los Angeles Abrasion Value

All the tested aggregates (Half Seed Shell and Quarter Seed Shells) are within limits of the recommended specification. The presence of lignin and cellulose in the seed shell contributes to the shell's rigidity and strength (Dai, Chen and Wei, 2023) this improves its performance when loaded and leads to lower LAA values.

Soundness Test

All the tested aggregates (Half Seed Shell and Quarter Seed Shells) are within limits of the recommended specification.

Silt Content

The tested fine Aggregates are within the limits of the recommended specification.

B. Specific Objective 2: To determine the mechanical properties of concrete that constitutes kukui seed shells

The mechanical property data for concrete containing kukui seed shells was statistically analyzed to determine the mean, standard deviation (SD), coefficient of variation (CV), and 95 % confidence limits. Each partial mix mix (0 %, 25 %, 50 %, 75 %, 100 %) was represented by three specimens per test age (either 7 days or 28 days). The calculations are shared in **Appendix A.3**

4.2.4 Properties of concrete which uses kukui seed shells as a replacement for coarse aggregates

Partial replacement of the coarse aggregates with kukui seed shells (Half Seed Shells (HSS) and Quarter Seed Shells (QSS)) of 0%, 25%, 50%, 75 % and 100% was carried out. The different weights of the constituents of the concrete in the respective partial replacement percentages were determined from the mix design. A detailed breakdown of each mix design is shared in **Appendix A.3**. Tests were carried out on wet and dry concrete.

4.3 Mix design

The mix design was developed with reference to the recommended design strength of 25MPa (C25). For consistency, the water cement ratio was kept constant throughout all the partial replacement mixes. **Table 4-8** below shows the summary of weights that were used for the mix design for different partial replacement percentages:

Table 4- 8: Material weights for partial replacement percentages

No.	Mechanical Test	Total material weights (kgs)					
		Cement	Fine Aggregates	Coarse Aggregates	Quarter Size Shell (QSS)	Half Size Shell (HSS)	Water
1	Compressive strength (6 cubes) – 7 and 28 days	96.84	162.45	124.79	24.74	58.51	48.42
2	Splitting Tensile Strength (3 cylinders) – 28 days	24.21	40.59	31.2	10.3	10.5	12.06
3	Flexural Strength (3 beams) – 28 days	193.59	324.9	249.57	82.46	84.06	96.84
4	Modulus of Elasticity (3 cubes) – 28 days	48.42	81.18	62.4	20.61	21.01	24.21
5	Fire resistance test (3 cubes) – 28 days	48.42	81.18	62.4	20.61	21.01	24.21
6	Thermal Conductivity test (3 cubes) – 28 days	48.42	81.18	62.4	20.61	21.01	24.21
7	Water Absorption test (3 cubes) – 28 days	48.42	81.18	62.4	20.61	21.01	24.21

4.3.1 Tests on wet/ fresh concrete

The main test carried out on the wet concrete was a slump test to test the consistency and workability of the fresh concrete. In the mix design, the author had assumed a slump of between 30-60 mm as an ideal requirement. **Table 4-9** below shows the slump values for the different concrete partial replacement designs:

Table 4- 9: Slump test results for different mixes

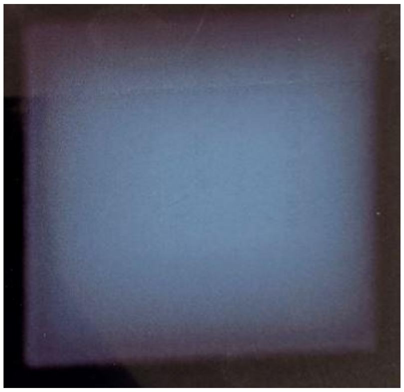
No.	Material	Slump (mm)
1.0	Control mix (100% Coarse Aggregates)	60
2.0	Mix 1 (25% Quarter Seed Shells & 75% Coarse Aggregates)	48
3.0	Mix 2 (50% Quarter Seed Shells & 50% Coarse Aggregates)	10
4.0	Mix 3 (75% Quarter Seed Shells & 25% Coarse Aggregates)	0
5.0	Mix 4 (100% Quarter Seed Shells)	0
6.0	Mix 5 (25% Half Seed Shells & 75% Coarse Aggregates)	25
7.0	Mix 6 (50% Half Seed Shells & 50% Coarse Aggregates)	5
8.0	Mix 7 (75% Half Seed Shells & 25% Coarse Aggregates)	0
9.0	Mix 8 (100% Half Seed Shells)	0

The reduction in slump is mainly due to the increased percentage of highly absorptive aggregates (Mehta and Monteiro, 2014) ie the kukui seed shells. This high absorption rate affects the water cement ratio and causes lower slump values.

4.3.2 Tests on hardened concrete

Internal topography of the concrete cube

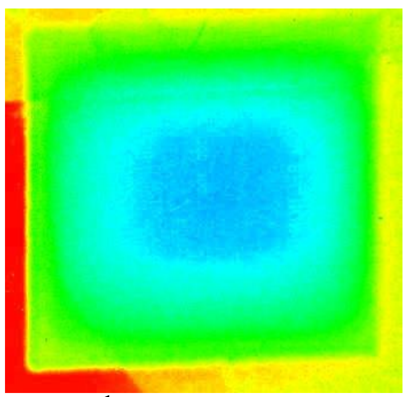
The Digital Xray machine was used to scan the concrete cubes and the output was shared. The output from the X-ray machine needed processing so that it can easily be presented in the report. ImageJ was used as an image processor to aid in interpretation of the voids within the cubes. **Figures 4-8** and **4-9** show the distribution of air voids within the Quarter Seed Shell (QSS) concrete and Half Seed Shell (HSS) concrete respectively.

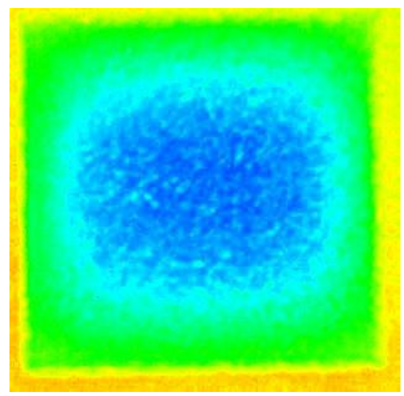


(a) Control sample

(b) 100% QSS sample

Before Image Processing





1

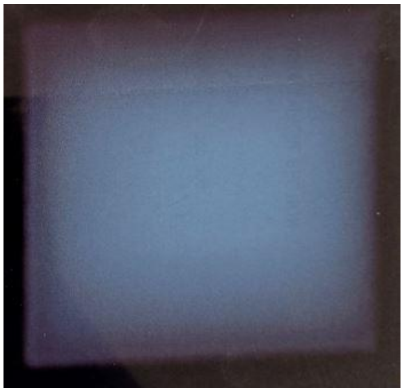
SS sample

sample

After Image processing

Figure 4- 8: Distribution of voids in control vs 100% QSS sample

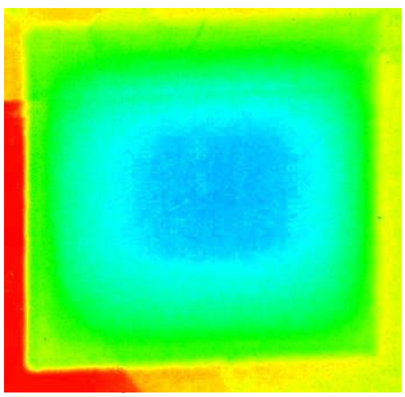
It was observed that the 100% QSS samples have small but visible voids compared to the Control Sample.

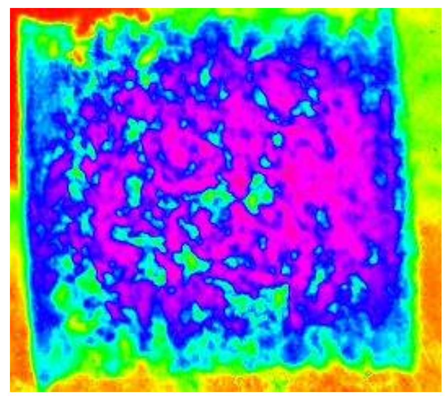


(a) Control sample

(b) 100% HSS sample

Before Image Processing





l sample

SS sample

After Image processing

Figure 4- 9: Distribution of voids in control vs 100% HSS sample

The examination of the high-resolution images of the specimen above, through distinguishing differences in color, informs the software in identification of voids or pores within the concrete matrix. This allows for an assessment of porosity. It was observed that the 100% HSS samples have large and visible voids compared to the Control Sample. The 100% HSS samples have more voids compared to the 100% QSS sample. The presence of these voids will affect the mechanical properties of the concrete.

Density

During execution of the different tests on the concrete, the concrete cubes, beams and cylinders were weighed and densities were derived. **Fig. 4-10** and **Fig. 4-11** show the variation of this density with the increase in Quarter Seed Shells (QSS) and Half Seed Shells (HSS) respectively.

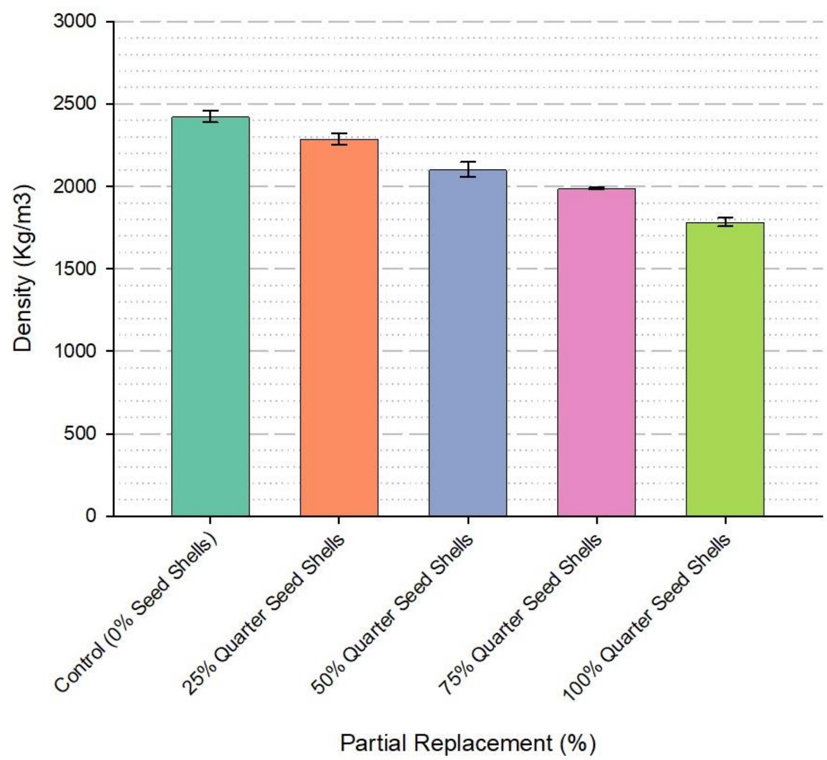


Figure 4- 10: Variation of density with Quarter Seed Shells (QSS) percentages

It was observed that as the percentage of Quarter Seed Shells (QSS) increased, the density of the concrete reduced. There is a **21%** reduction in density from the control mix to **100% QSS**.

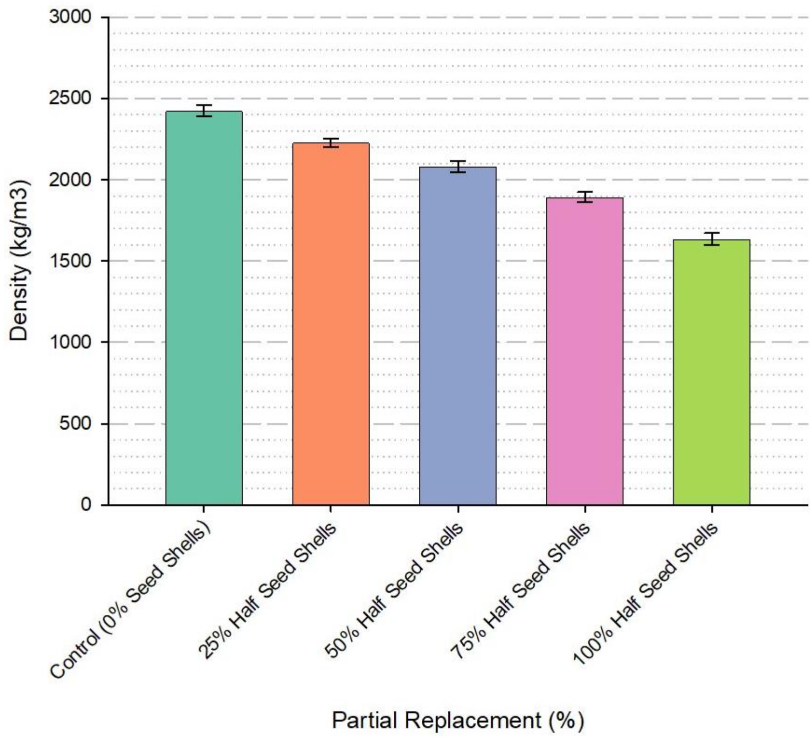


Figure 4- 11: Variation of density with Half Seed Shells (HSS) percentages

It was observed that as the percentage of Half Seed Shells (HSS) increased, the density of the concrete reduced. There is a **29%** reduction in density from the control mix to **100% HSS**. Generally, the use of HSS in the concrete leads to a less dense concrete compared to using QSS.

The lower densities in the HSS in relation to the QSS is attributed to the increased number of voids in the HSS compared to the QSS. This leads to concrete of lower density.

Compressive Strength Tests

This test was carried out at 7 and 28 days. **Figure 4-12 and 4-13** below shows the average Compressive Strength of the cubes for different partial replacement percentages for the Half Size Shells (HSS) and Quarter Seed Shells (QSS) after 7 and 28 days respectively.

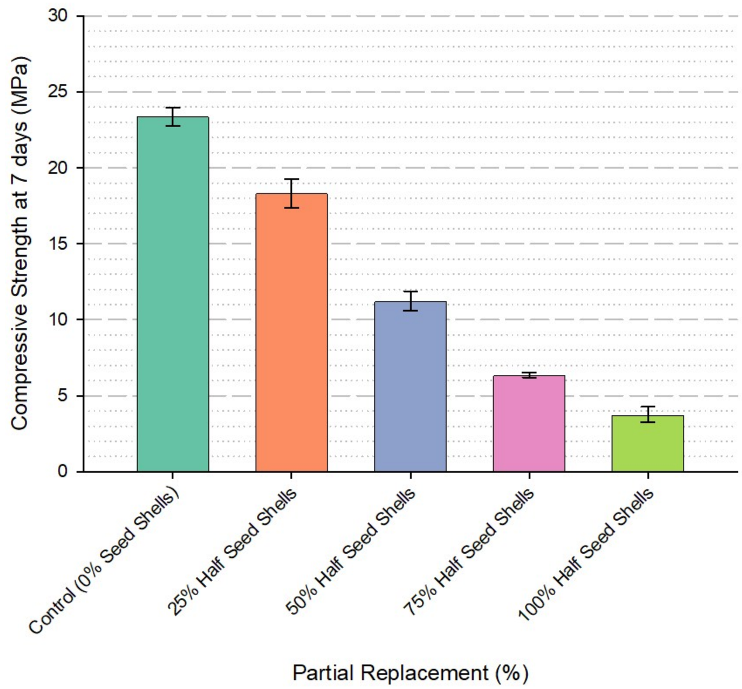


Figure 4- 12: Variation of Compressive Strength with Half Seed Shell partial replacement after 7 days

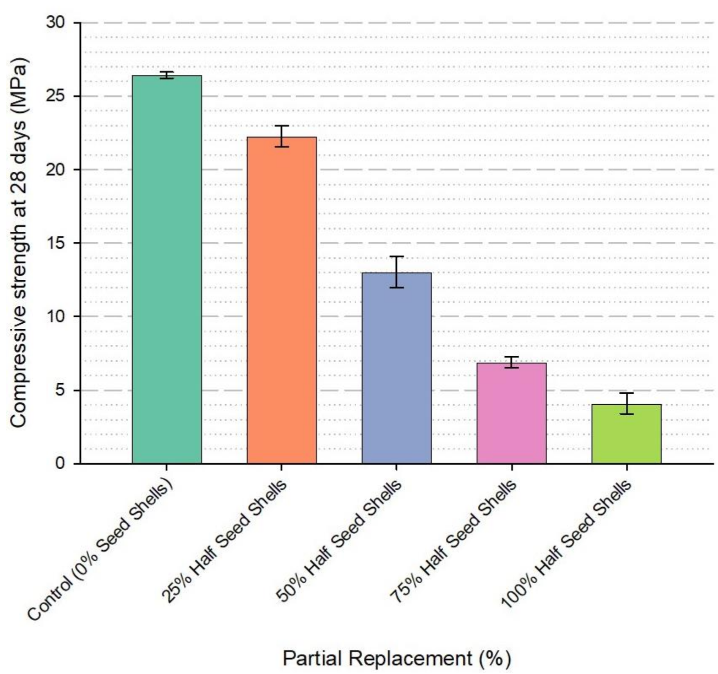


Figure 4- 13: Variation of Compressive Strength with Half Seed Shell partial replacement after 28 days

It was observed that there is an average of **84%** loss in compressive strength when using **HSS** in concrete from the control to the use of 100% HSS.   .

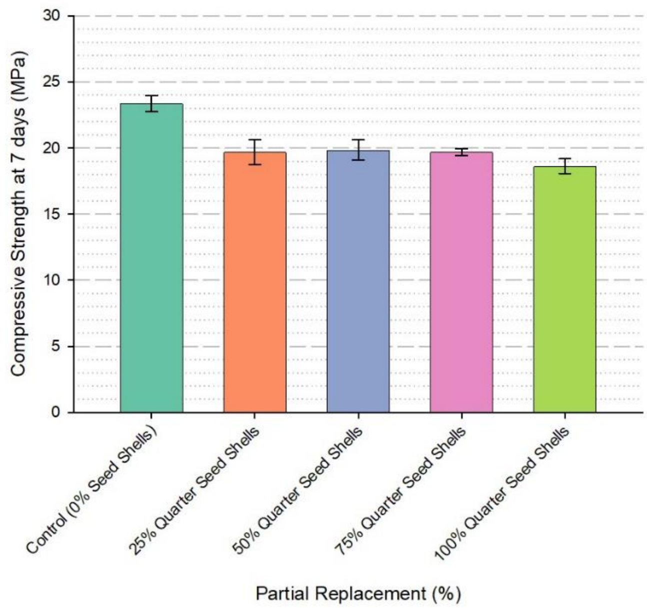


Figure 4- 14: Variation of Compressive Strength with Quarter Seed Shell partial replacement after 7 days

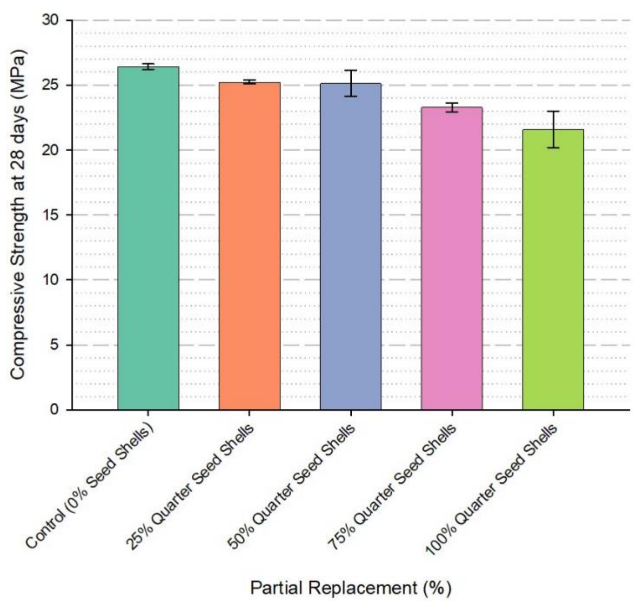


Figure 4- 15: Variation of Compressive Strength with Quarter Seed Shell partial replacement after 28 days

It was also observed that there is an average of **18%** loss in compressive strength when using **QSS** in concrete from the control to the use of 100% QSS. Generally, using QSS in concrete produces concrete with a higher compressive strength compared to HSS. 25% QSS and 50% QSS being above 25MPa which was the design concrete strength.

This reduction in Compressive Strength is attributed to the presence of voids within the concrete that led to a decrease in this strength. These voids could be attributed to increased pore area in the inter-facial zone in concrete (microscopic zone between the aggregate and cement paste in concrete) (Lo et al., 2008). Additionally, due to the fact that during analysis of the grading of the material, it was observed that the material is uniformly graded leading to poor packing of the aggregates within the concrete matrix due to missing aggregate sizes (Mehta and Monteiro, 2014) leading to honey combs. The most affected percentages were the 75% HSS and 100%. **Figure 4-16** below shows images of the 75% HSS and 100% HSS cubes after removing them from the respective moulds.

75% HSS

100% HSS

Figure 4- 16: Images of the 75% HSS and 100% HSS cubes after removing moulds

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the compressive strength of the concrete are shown in the Table 4-10 below:

Table 4- 10: Statistical data for compressive strength results of Half Seed Shells in concrete at 7 days

S/N	Sample	Standard deviation (MPa)	Mean (MPa)	Confidence interval (MPa)	
1	Control	0.5	23.37	23.37±1.24	Low standard deviation
2	25% Quarter Seed Shells	0.77	19.7	19.7±1.94	Low standard deviation
3	50% Quarter Seed Shells	0.62	19.87	19.87±1.55	Low standard deviation
4	75% Quarter Seed Shells	0.22	19.7	19.7±0.54	Low standard deviation
5	100% Quarter Seed Shells	0.45	18.6	18.6±1.12	Low standard deviation
6	25% Half Seed Shells	0.78	18.3	18.3±1.93	Low standard deviation
7	50% Half Seed Shells	0.53	11.23	11.23±1.32	Low standard deviation
8	75% Half Seed Shells	0.12	6.37	6.37±0.31	Low standard deviation
9	100% Half Seed Shells	0.41	3.77	3.77±1.02	Low standard deviation

Table 4- 11: Statistical data for the compressive strength results of Quarter Seed Shells in concrete at 28 days

S/N	Sample	Standard deviation (MPa)	Mean (MPa)	Confidence interval (MPa)	Comment
1	Control	0.17	26.43	26.43±0.42	Low standard deviation
2	25% Quarter Seed Shells	0.12	25.23	25.23±0.31	Low standard deviation
3	50% Quarter Seed Shells	0.82	25.13	25.13±2.03	Low standard deviation
4	75% Quarter Seed Shells	0.28	23.3	23.3±0.7	Low standard deviation
5	100% Quarter Seed Shells	1.14	21.6	21.6±2.84	Low standard deviation
6	25% Half Seed Shells	0.57	22.3	22.3±1.42	Low standard deviation
7	50% Half Seed Shells	0.86	13.03	13.03±2.13	Low standard deviation
8	75% Half Seed Shells	0.29	6.9	6.9±0.73	Low standard deviation
9	100% Half Seed Shells	0.57	4.1	4.1±1.42	Low standard deviation

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for compression at 7 days and 28 days. A low standard deviation indicates the data points are closely packed. This means they are highly reliable.

Flexural Strength

This test was carried out at 28 days. **Figure 4-17** below shows the average Flexural Strength of the beams for different partial replacement percentages for the Half Size Shells (HSS) after 28 days.

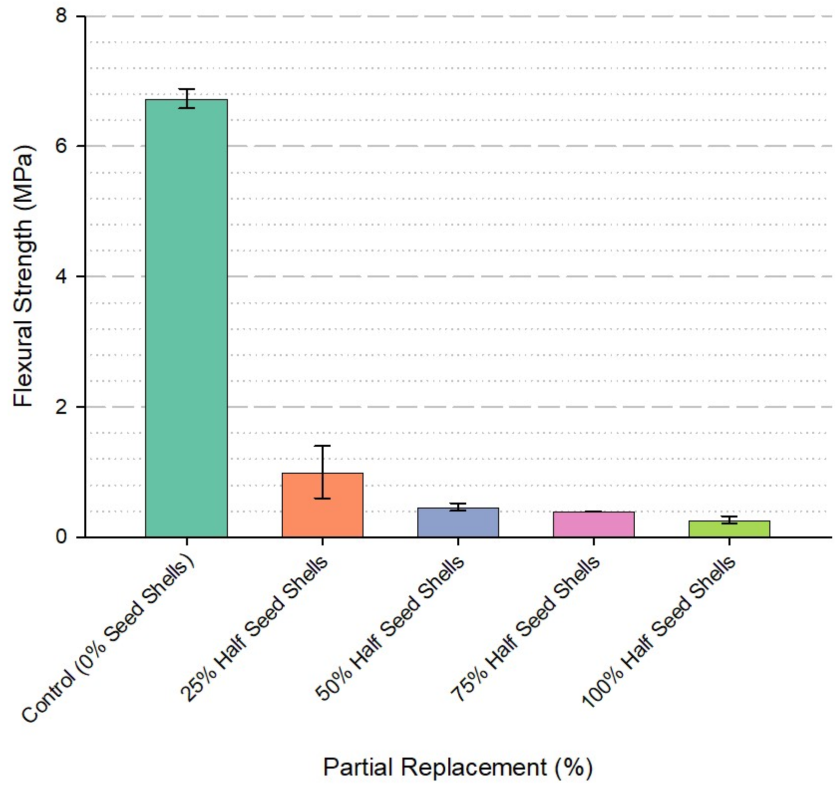


Figure 4- 17: Variation of Flexural Strength with Half Seed Shells (HSS) percentages at 28 days

It was observed that as the percentage of **HSS** increased, the Flexural Strength of the concrete reduced. There is a **96%** reduction in Flexural Strength from the control mix to 100% HSS.

Figure 4-18 below shows the average Flexural Strength of the beams for different partial replacement percentages for the Quarter Size Shells (QSS) after 28 days.

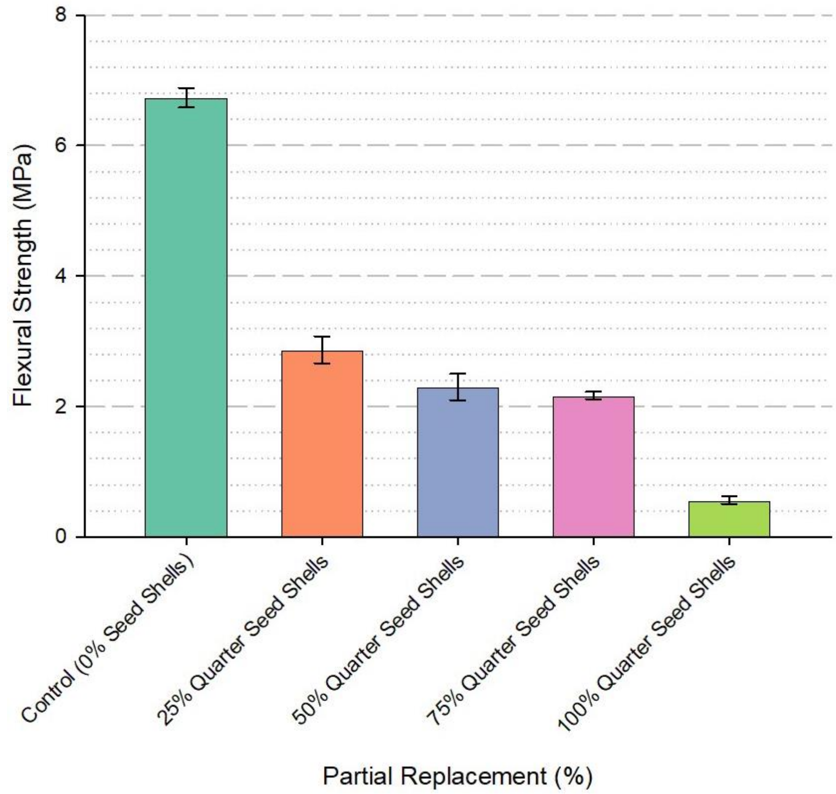


Figure 4- 18: Variation of Flexural Strength with Quarter Seed Shells (QSS) percentages at 28 days

It was observed that as the percentage of **QSS** increased, the Flexural Strength of the concrete reduced. There is a **91%** reduction in Flexural Strength from the control mix to 100% QSS. Generally, the use of QSS in the concrete produces better Flexural Strength results compared to using HSS.

The lower Flexural Strength values for the Half Seed Shell (HSS) and Quarter Seed Shell (QSS) in relation to normal coarse aggregates is attributed to the seed's smooth surface. The smooth surface affects the bond strength hence reducing the Flexural Strength of the concrete (Mehta and Monteiro, 2014).

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the flexural strength of the concrete are shown in the **Table 4-12** below:

Table 4- 12: Statistical data for flexural strength results for concrete with partial replacement of Quarter and Half Seed Shells

S/N	Sample	Standard deviation (MPa)	Mean (MPa)	Confidence interval (MPa)	
1	Control	0.11	6.76	6.76±0.29	Low standard deviation
2	25% Quarter Seed Shells	0.19	2.86	2.86±0.46	Low standard deviation
3	50% Quarter Seed Shells	0.14	2.3	2.3±0.34	Low standard deviation
4	75% Quarter Seed Shells	0.03	2.17	2.17±0.06	Low standard deviation
5	100% Quarter Seed Shells	0.04	0.59	0.59±0.09	Low standard deviation
6	25% Half Seed Shells	0.33	1.01	1.01±0.81	Low standard deviation
7	50% Half Seed Shells	0.05	0.45	0.45±0.13	Low standard deviation
8	75% Half Seed Shells	0.02	0.42	0.42±0.04	Low standard deviation
9	100% Half Seed Shells	0.05	0.25	0.25±0.12	Low standard deviation

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for Flexural Strength at 28 days. A low standard deviation indicates the data points are closely packed. This means they are highly reliable.

Splitting Tensile Strength

This test was carried out at 28 days. **Figures 4-19 and 4-20** below show the average Splitting Tensile Strength of the cylinders for different partial replacement percentages for the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) after 28 days.

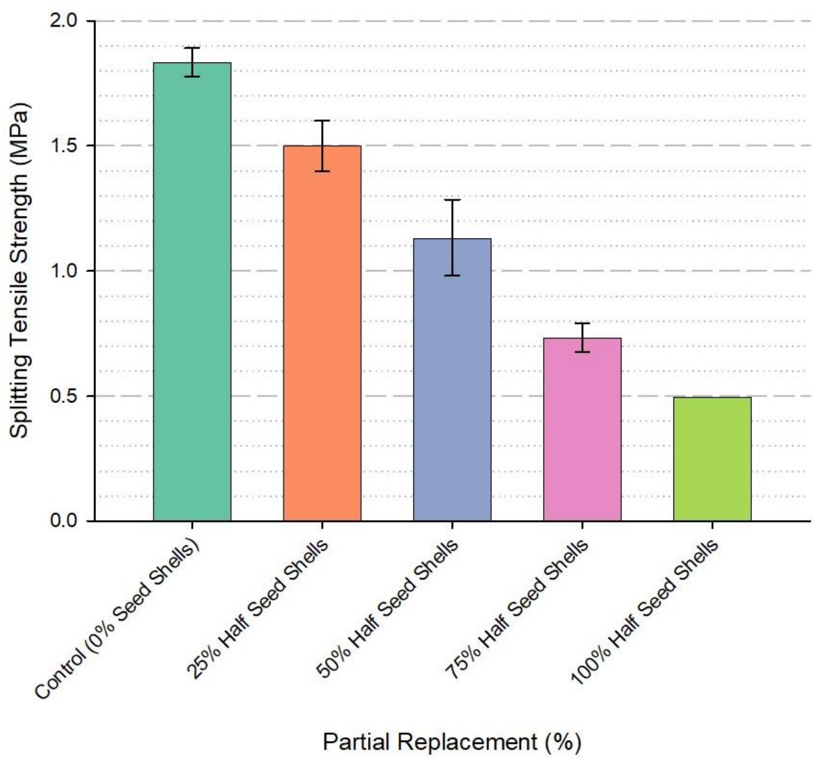


Figure 4- 19: Variation of Splitting Tensile Strength with Half Seed Shells (HSS) percentages at 28 days

It was observed that as the percentage of **HSS** increased, the Splitting Tensile Strength the concrete reduced. There is a **74%** reduction in Splitting Tensile Strength from the control mix to 100% HSS.

Figure 4-20 below shows the average Splitting Tensile Strength of the cylinders for different partial replacement percentages for the Quarter Seed Shells (QSS) after 28 days.

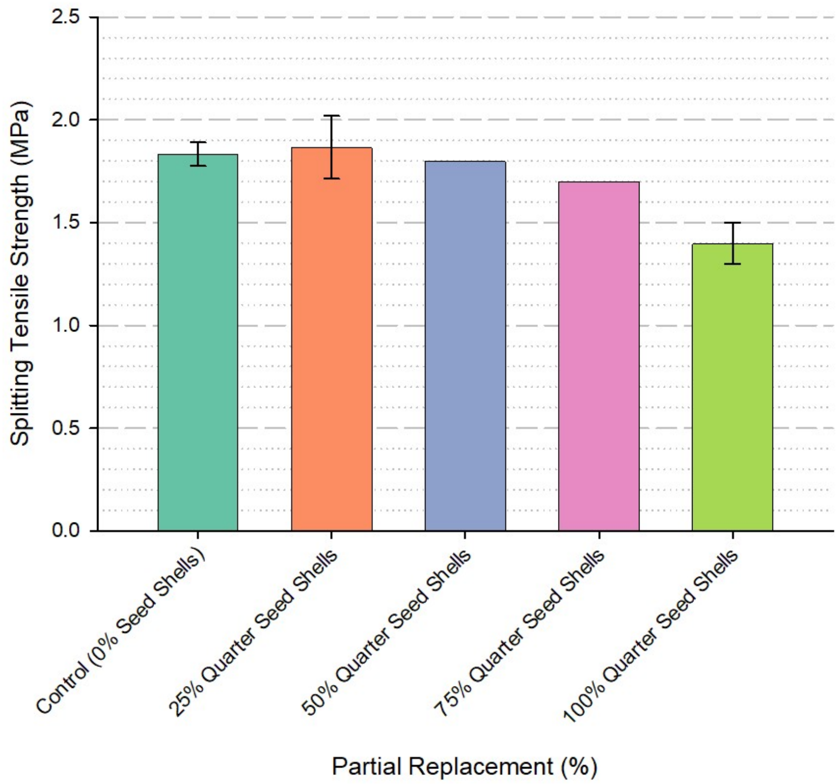


Figure 4- 20: Variation of Splitting Tensile Strength with Quarter Seed Shells (QSS) percentages at 28 days

It was observed that as the percentage of **QSS** increased, the Splitting Tensile Strength of the concrete reduced. There is a **21%** reduction in Splitting Tensile Strength from the control mix to 100% QSS. Generally, the use of QSS in the concrete produces better Splitting Tensile Strength results compared to using HSS.

The lower Splitting Tensile Strength values for the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) is attributed to the seed's smooth surface. The smooth surface affects the bond strength hence reducing the Splitting Tensile Strength of the concrete (Mehta and Monteiro, 2014).

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the splitting tensile of the concrete are shown in the Table below:

Table 4- 13.: Statistical data for splitting tensile results

S/N	Sample	Standard deviation (MPa)	Mean (MPa)	Confidence interval (MPa)	
1	Control	0.047	1.83	1.83±0.12	Low standard deviation
2	25% Quarter Seed Shells	0.124	1.87	1.87±0.31	Low standard deviation
3	50% Quarter Seed Shells	0.002	1.8	1.8±0	Low standard deviation
4	75% Quarter Seed Shells	0.001	1.7	1.7±0	Low standard deviation
5	100% Quarter Seed Shells	0.08	1.4	1.4±0.2	Low standard deviation
6	25% Half Seed Shells	0.08	1.5	1.5±0.2	Low standard deviation
7	50% Half Seed Shells	0.12	1.13	1.13±0.31	Low standard deviation
8	75% Half Seed Shells	0.05	0.73	0.73±0.12	Low standard deviation
9	100% Half Seed Shells	0.001	0.5	0.5±0	Low standard deviation

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for Splitting Tensile Strength at 28 days. A low standard deviation indicates the data points are closely packed. This means they are highly reliable.

Modulus of Elasticity

This test was carried out at 28 days. **Figure 4-21** below shows the average Modulus of Elasticity values of the cubes for different partial replacement percentages for the Half Seed Shells (HSS) after 28 days.

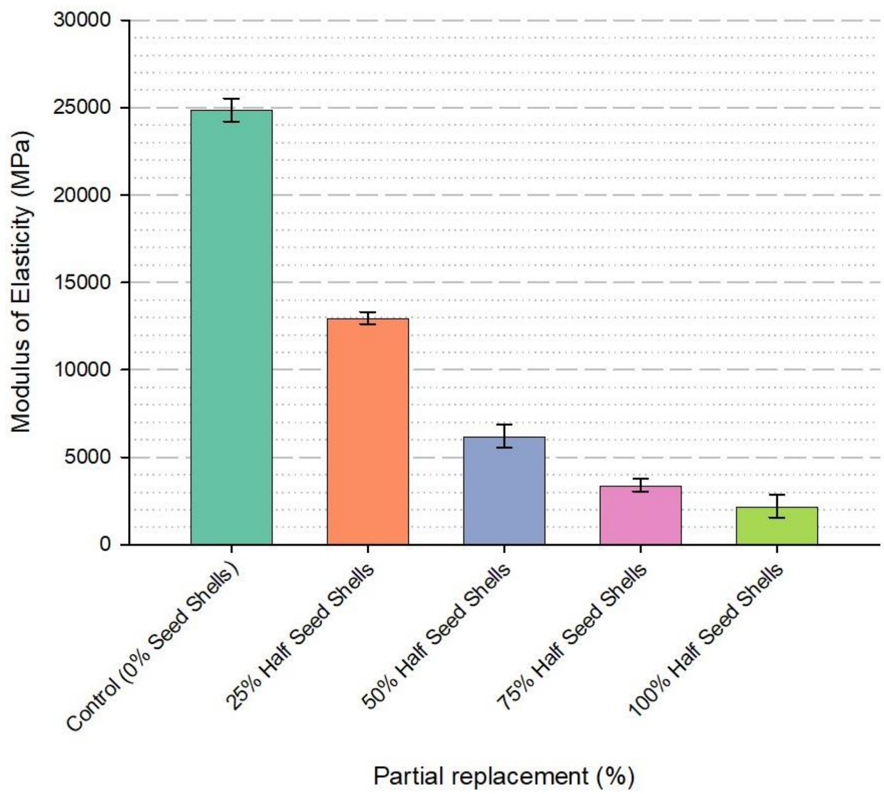


Figure 4- 21: Variation of Modulus of Elasticity with Half Seed Shells (HSS) percentages at 28 days

It was observed that as the percentage of **HSS** increased, the Modulus of Elasticity of the concrete reduced. There is a **92%** reduction in Modulus of Elasticity from the control mix to 100% HSS.

Figure 4-22 below shows the average Modulus of Elasticity of the cubes for different partial replacement percentages for the Quarter Seed Shells (QSS) after 28 days.

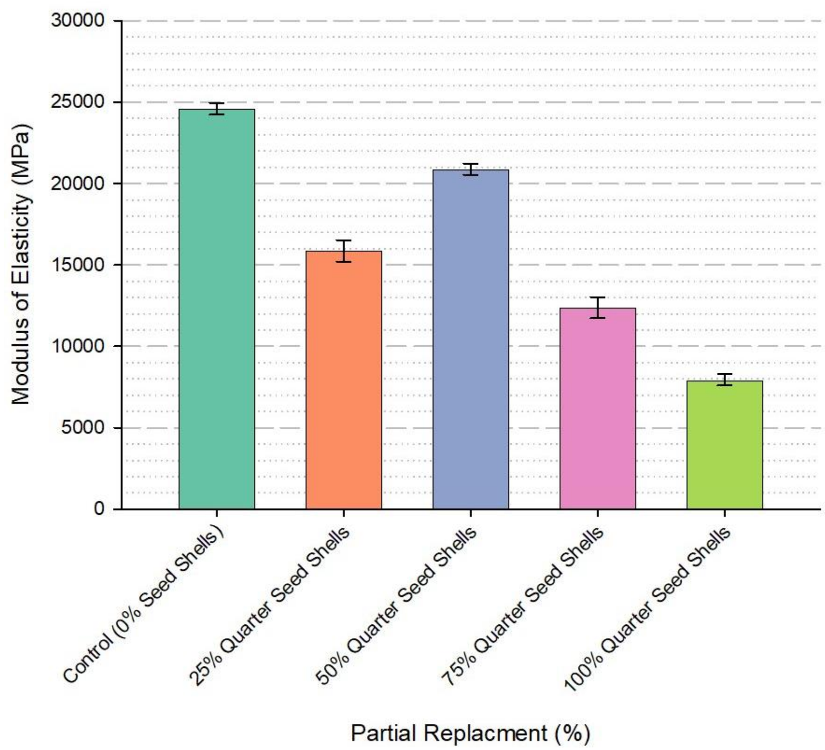


Figure 4- 22: Variation of Splitting Tensile Strength with Quarter Seed Shells (QSS) percentages at 28 days

It was observed that as the percentage of **QSS** increased, the Splitting Tensile Strength of the concrete reduced. There is a **67%** reduction in Splitting Tensile Strength from the control mix to 100% QSS. Generally, the use of Quarter Seed Shells (QSS) in the concrete has better Modulus of Elasticity results compared to using Half Seed Shells (HSS).

The lower Modulus of Elasticity values for the HSS in relation to the QSS is attributed to the increased number of voids in the HSS compared to the QSS. This leads to reduced resistance of the cubes to compressive stress (Mehta and Monteiro, 2014).

C. Specific Objective 3: To determine the durability performance of concrete that constitutes kukui seed shells

The mechanical property data for concrete containing kukui seed shells was statistically analyzed to determine the mean, standard deviation (SD), coefficient of variation (CV), and 95 % confidence limits. Each partial mix mix (0 %, 25 %, 50 %, 75 %, 100 %) was represented by three specimens per test age (either 7 days or 28 days). The calculations are shared in **Appendix A.3** In order to determine the durability of concrete which uses kukui seed shells as a replacement for coarse aggregates, the tests below were carried out:

Water Absorption

This test was carried out at 28 days. **Figure 4-23** below shows the average Water Absorption of the beams for different partial replacement percentages for the Half Size Shells after 28 days.

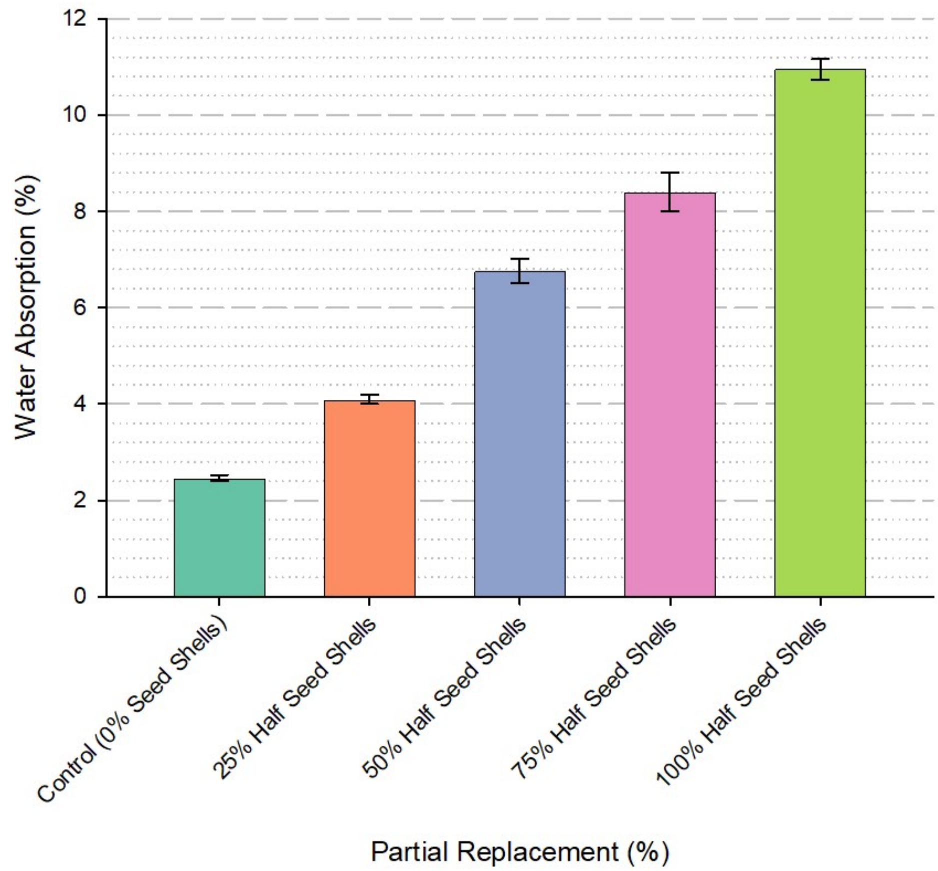


Figure 4- 23: variation of Water Absorption with Half Seed Shells (HSS) percentages at 28 days

It was observed that as the percentage of **HSS** increased, the Water Absorption of the concrete increased. There is a **332%** increase in Water Absorption from the control mix to 100% HSS.

Figure 4-24below shows the average Water Absorption of the cubes for different partial replacement percentages for the Quarter Seed Shells (QSS) after 28 days.

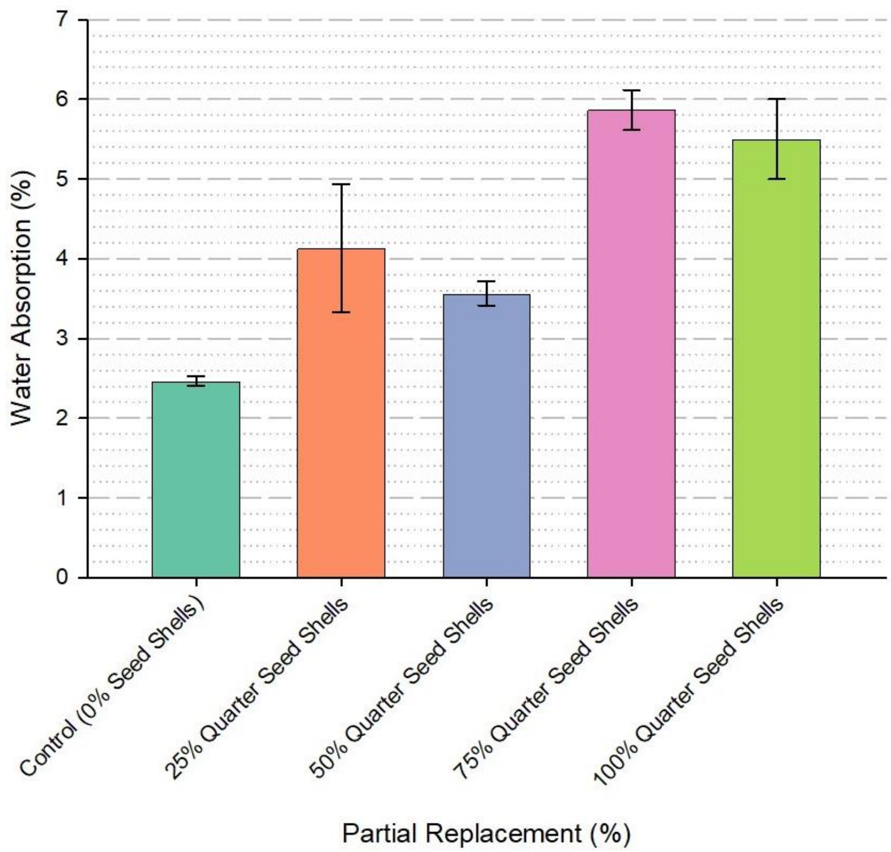


Figure 4- 24: Variation of Water Absorption with Quarter Seed Shells (QSS) percentages at 28 days

It was observed that as the percentage of **QSS** increased, the Water Absorption of the concrete increased. There is a **120%** increase in Water Absorption from the control mix to 100% QSS. Generally, the use of QSS in the concrete produces better Water Absorption results compared to using HSS.

The higher Water Absorption values for the HSS in relation to the QSS is attributed to the increased number of voids in the HSS compared to the QSS. The voids are a source for water to be retained in the concrete when damp.

It was further observed that after oven drying the soaked concrete cubes, cracks were observed on all the cubes except the control concrete and the concrete that had 25% Quarter Seed Shells. These cracks should be attributed to the difference in thermal expansion properties of the constituents of the concrete leading to the development of cracks ((Kosmatka et al., 2017). **Figure 4-25** below shows images of some of the cracked concrete cubes.

Figure 4- 25: Cracked concrete cubes

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the Water Absorption of the concrete are shown in the Table. below:

Table 4- 14: Statistical data for Water Absorption results

S/N	Sample	Standard deviation (%)	Mean (%)	Confidence interval (%)	
1	Control	0.047	2.47	2.47±0.12	Low standard deviation
2	25% Quarter Seed Shells	0.65	4.13	4.13±1.63	Low standard deviation
3	50% Quarter Seed Shells	0.124	3.57	3.57±0.31	Low standard deviation
4	75% Quarter Seed Shells	0.21	5.87	5.87±0.51	Low standard deviation
5	100% Quarter Seed Shells	0.41	5.5	5.5±1.01	Low standard deviation
6	25% Half Seed Shells	0.08	4.1	4.1±0.2	Low standard deviation
7	50% Half Seed Shells	0.2	6.77	6.77±0.51	Low standard deviation
8	75% Half Seed Shells	0.33	8.4	8.4±0.81	Low standard deviation
9	100% Half Seed Shells	0.2	10.83	10.83±0.51	Low standard deviation

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for Water Absorption at 28 days. A low standard deviation indicates the data points are closely packed. This means they are highly reliable.

Thermal Conductivity

This test was carried out at 28 days. **Figure 4-25** below shows the average Thermal Conductivity of the concrete for different partial replacement percentages for the Half Seed Shells (HSS) after 28 days.

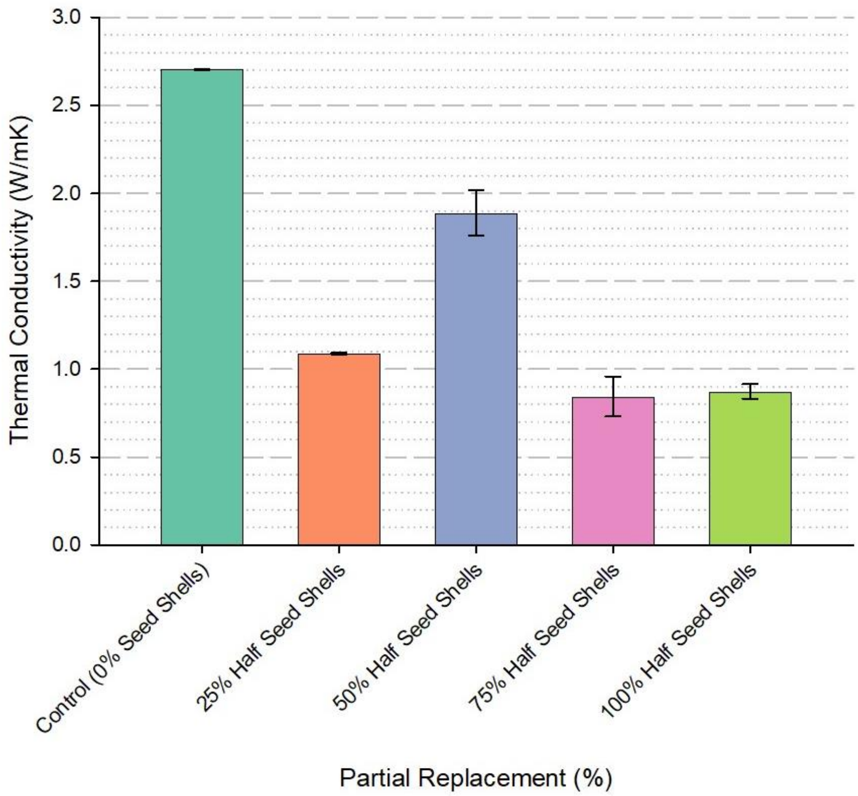


Figure 4- 26: Variation of Thermal Conductivity with Half Seed Shells (HSS) percentages at 28 days

It was observed that as the percentage of **HSS** increased, the Thermal Conductivity of the concrete reduced. There is a **68%** reduction in Thermal Conductivity from the control mix to 100% HSS.

Figure 4-27 below shows the average Thermal Conductivity of the concrete for different partial replacement percentages for the Quarter Seed Shells (QSS) after 28 days.

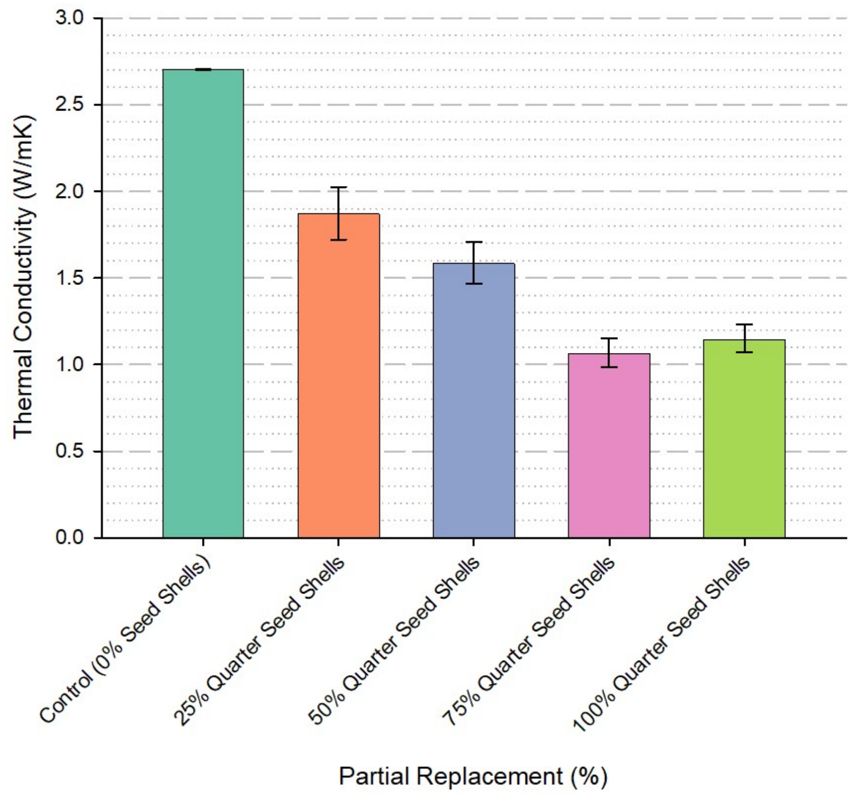


Figure 4- 27: Variation of Thermal Conductivity with Quarter Seed Shells (QSS) percentages at 28 days

It was observed that as the percentage of **QSS** increased, the Thermal Conductivity of the concrete reduced. There is a **57%** reduction in Thermal Conductivity from the control mix to 100% QSS. Generally, the use of HSS in the concrete produces better Thermal Conductivity results compared to using QSS.

The better Thermal Conductivity values for the HSS in relation to the QSS is attributed to the increased number of voids in the HSS compared to the QSS. The voids hinder the transfer of heat within the concrete (Mindess et al., 2003).

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the thermal conductivity of the concrete are shown in the Table. below:

Table 4- 15: Statistical data for thermal conductivity results

S/N	Sample	Standard deviation (W/mK)	Mean (W/mK)	Confidence interval (W/mK)	
1	Control	0.002	2.7	2.7±0	Low standard deviation
2	25% Quarter Seed Shells	0.12	1.87	1.87±0.31	Low standard deviation
3	50% Quarter Seed Shells	0.099	1.59	1.59±0.25	Low standard deviation
4	75% Quarter Seed Shells	0.067	1.067	1.067±0.17	Low standard deviation
5	100% Quarter Seed Shells	0.065	1.14	1.14±0.16	Low standard deviation
6	25% Half Seed Shells	0.003	1.09	1.09±0.01	Low standard deviation
7	50% Half Seed Shells	0.104	1.9	1.9±0.26	Low standard deviation
8	75% Half Seed Shells	0.09	0.84	0.84±0.23	Low standard deviation
9	100% Half Seed Shells	0.03	0.87	0.87±0.08	Low standard deviation

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for Thermal Conductivity at 28 days. A low standard deviation indicates the data points are closely packed. This means they are highly reliable.

Fire Resistance

Under the fire resistance test, the cube is fired until a given temperature and on removal from the kiln, its compressive strength is measured. **Fig.4-27** shows the graph showing the temperature, vs compressive strength ratios readings that are expected of the cube after being removed from the kiln. Since we are dealing with lightweight aggregate concrete, line b is considered

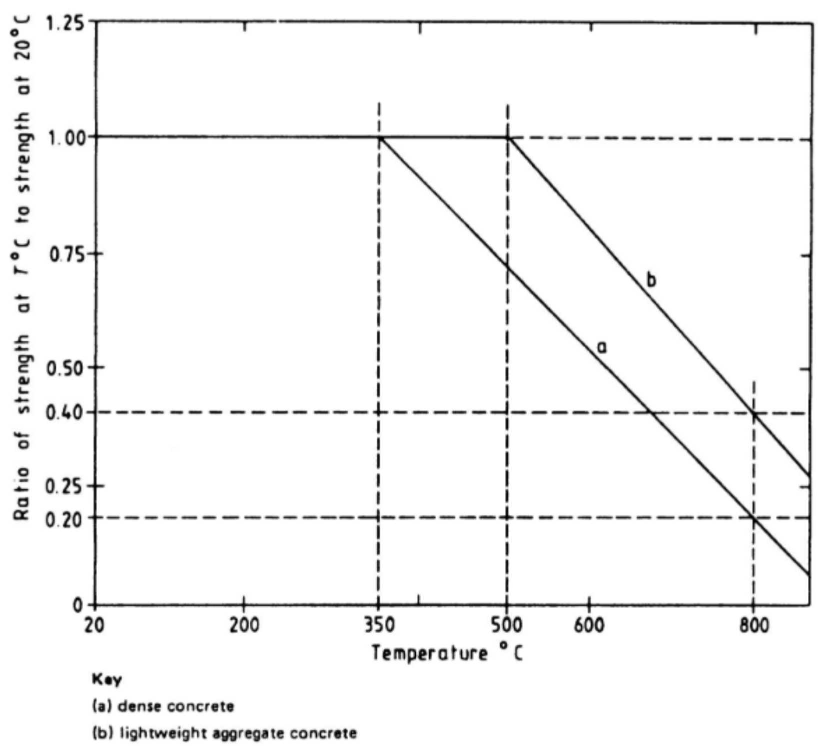


Figure 0-27: Design curves for variation of concrete strength with temperature (BS8110-2:1985: fig.4.4)

The concrete cubes were fired to a temperature of 250°C in a ceramic kiln (Kingery et al., 1976). **Figures 4-28 and 4-29** show the effects of heating the specimen for 8 hours

25% Half Seed Shells (HSS) 100% Half Seed Shells (HSS)

Figure 4- 28: 25% HSS and 100% HSS after being fired at 250°C for 12 hours

25% Quarter Seed Shells (QSS) 100% Quarter Seed Shells (QSS)

Figure 4- 29: 25% QSS and 100% QSS after being fired at 250°C for 12 hours

Both the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) disintegrated when removed from the kiln. From BS81110-2:1985: Fig 4.4, Light Weight Aggregate Concrete are supposed to maintain their compressive strength until temperatures of 500°C, unfortunately, the samples failed the fire resistance test.

D. Specific Objective 4: To use finite element analysis to investigate the serviceability performance of a concrete structural element that makes up kukui seed shells under loading

Finite Element Analysis of Structural Modal

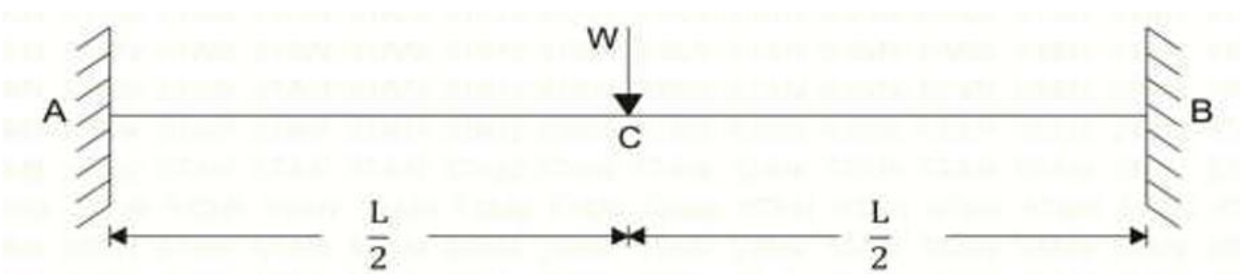


Figure 4- 30: Illustration of fixed ended beam considered during the analysis

Fig. 4.28 above shows the structural element setup that was considered in the simulation process

Mechanical properties of concrete used in ANSYS

When developing the modeling ANSYS, the program prompted for engineering constants to aid in its analysis. The **Table 4.10** below shows the mechanical properties used as engineering constants used during the simulation process.

Table 4- 16: Mechanical properties used as Engineering constants in ANSYS

No.	Sample code	Material tests					
		Compressive Strength at 28 days (Mpa)	**Flexural Strength (Mpa)**	**Splitting Tensile Strength (Mpa)**	**Young's Modulus of Elasticity (Mpa)**	**Density (kg/m3)**	**Poisson's ratio**
1	100% of Coarse Aggregates	26.4	6.8	1.9	24,750	2,367	0.3
2	25% of Quarter Seed Shells	25.2	2.9	1.9	15,750	2,219	
3	50% of Quarter Seed Shells	25.1	2.3	1.8	21,034	2,112	
4	75% of Quarter Seed Shells	23.3	2.2	1.7	12,263	1,982	
5	100% of Quarter Seed Shells	21.6	0.6	1.4	8,100	1,834	
6	25% of Half Seed Shells	22.3	1	1.5	13,118	2,255	
7	50% of Half Seed Shells	13	0.5	1.1	6,094	2,004	
8	75% of Half Seed Shells	6.9	0.4	0.7	3,569	1,876	
9	100% of Half Seed Shells	4.1	0.3	0.5	2,085	1,641	

4.3.1.1 Deformation output

The **Table 4-17** below shows different deformation outputs for the different loads on the different beams that were developed for the simulation.

Table 4- 17: ANSYS beam deformation output

No.	Material	Deflection due to point load (mm)			
		5,000N	10,000N	15,000N	20,000N
1	100% Coarse Aggregate	0.010102	0.020205	0.030307	0.04041
2	25% Quarter Seed Shell	0.015875	0.031751	0.047626	0.063501
3	50% Quarter Seed Shell	0.011887	0.023775	0.035662	0.047549
4	75% Quarter Seed Shell	0.02039	0.040779	0.061169	0.081558
5	100% Quarter Seed Shell	0.030869	0.061797	0.092606	0.12347
6	25% Half Seed Shell	0.019061	0.038121	0.057182	0.076242
7	50% Half Seed Shell	0.04103	0.08206	0.12309	0.16412
8	75% Half Seed Shell	0.070058	0.14012	0.21017	0.28023
9	100% Half Seed Shell	0.11992	0.23984	0.35977	0.47969

Analysis of results

Fig. 4-31 and **Fig. 4-33** below show the different deformations extracted from ANSYS corresponding to the loads applied.

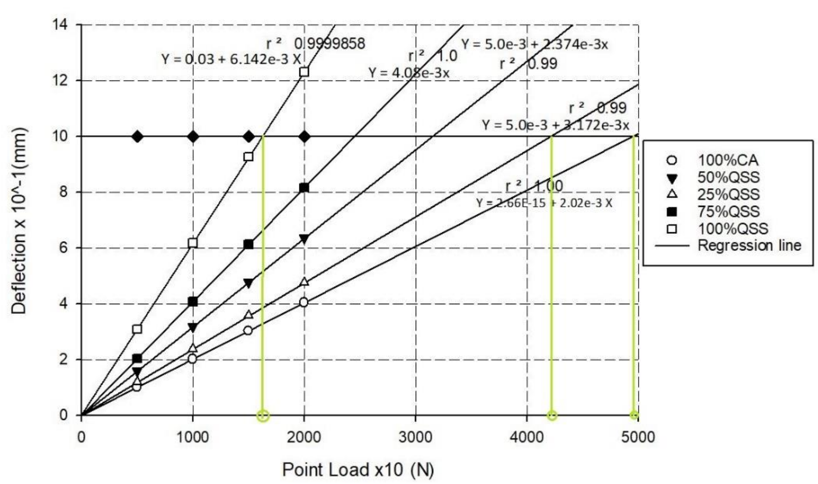


Figure 4- 31: Variation in deformation with applied loads on beams that have Quarter Seed Shells (QSS)

It was observed that the more Quarter Seed Shells (QSS) added to the concrete, the lower the load required to reach the maximum deflection of 10mm (serviceability limit).

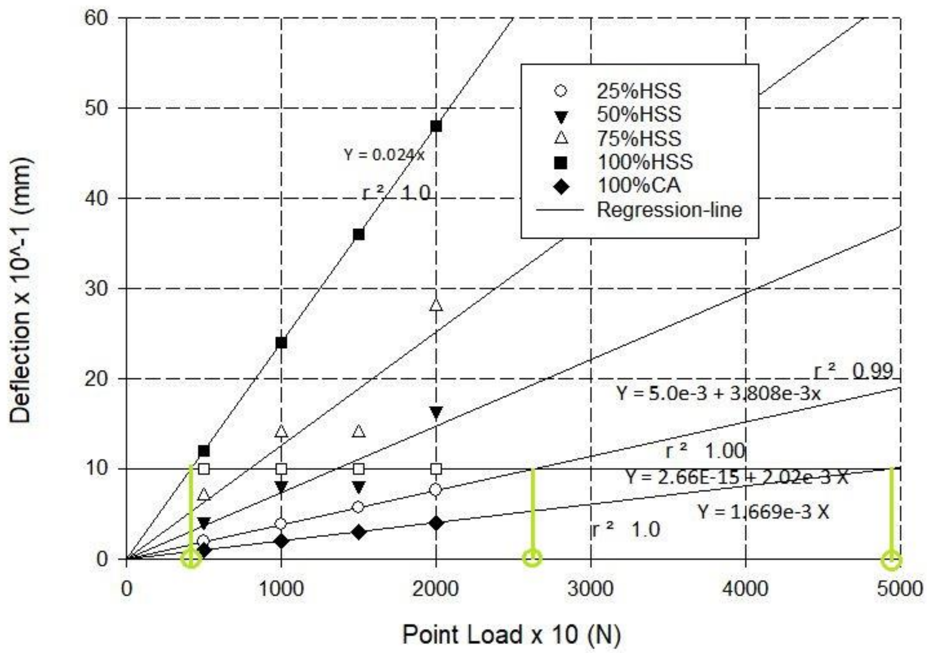


Figure 4- 32: Variation in deformation with applied loads on beams that have Half Seed Shells (QSS)

It was observed that the more Half Seed Shells (HSS) added to the concrete, the lower the load required to reach the maximum deflection of 10mm (serviceability limit). Generally, the Quarter seed shells (QSS) perform better than the Half Seed Shells (HSS).

During analysis of the results, the forces required for the Quarter Seed Shell beams and Half Seed Shell beams to reach the limit of 10mm were recorded and shared in **Fig.4-33** below.

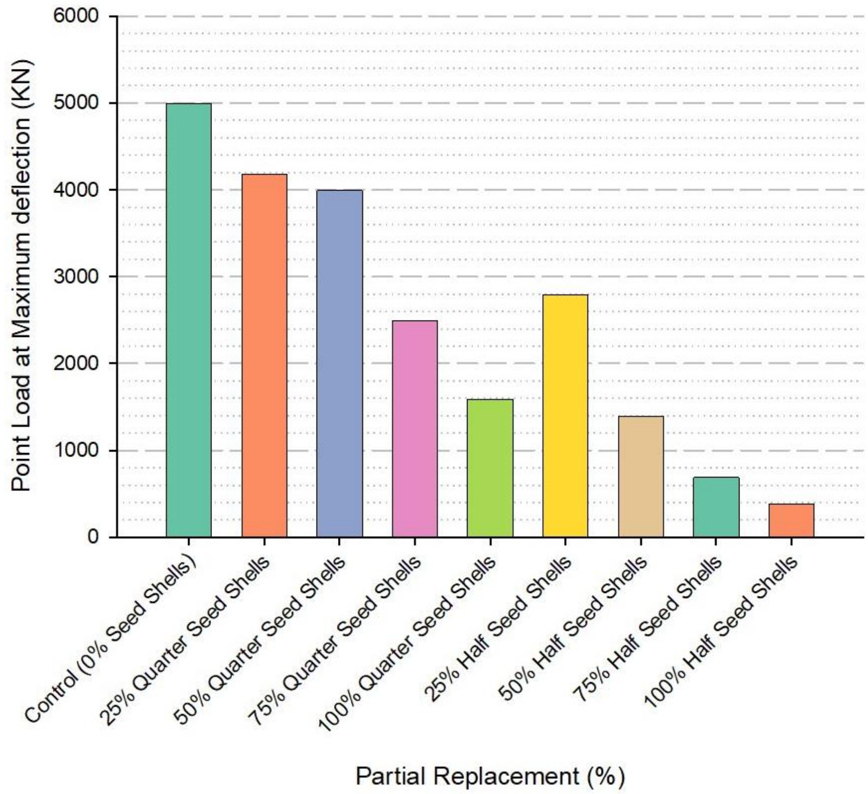


Figure 4- 33: Variation of Maximum point Load at 10mm deformation

It was observed that there is a **91% reduction** in the Load required to reach the 10mm deformation from the Control concrete to 100% Half Seed Shell Concrete (**HSS**). Additionally, there is a **67%** reduction in the Load required to reach the 10mm deformation from the Control concrete to 100% Quarter Seed Shell Concrete (**QSS**). Quarter Seed Shells (QSS) generally present better than Half Seed Shell concrete under deformation conditions due to their ability to perform better under loading.

An additional analysis was done on the maximum combined stress on the beam at maximum deflection. The **Fig 4-34** below shows the variation of maximum combined stress with partial replacement of the kukui seed shells.

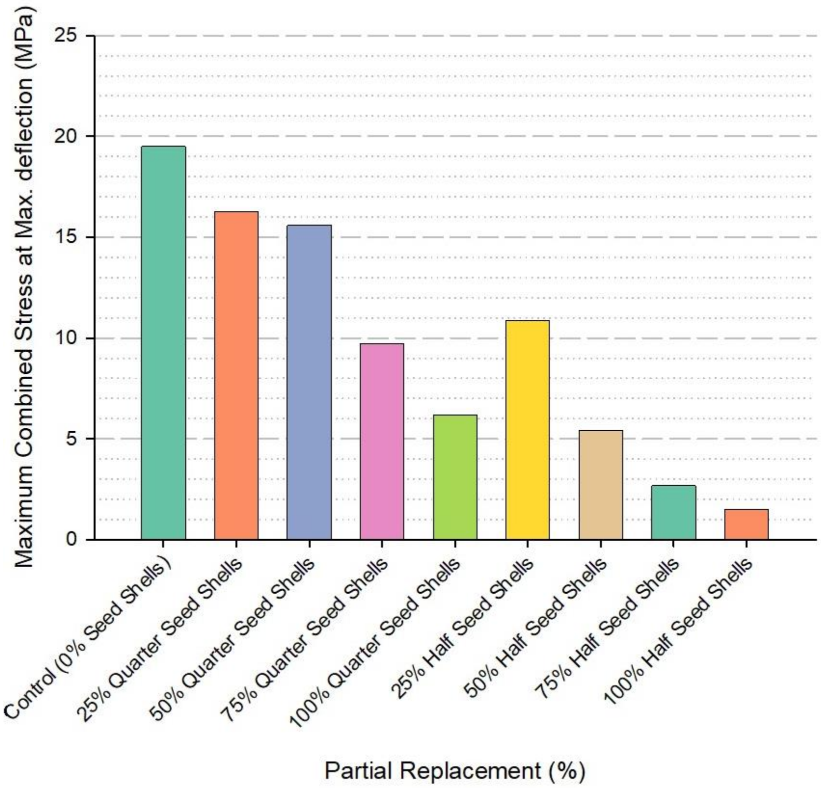


Figure 4- 34: Variation of Maximum Combined Stress at 10mm deformation

It is recommended to quarter seed shells in concrete as they can resist more loads and stresses compared to Half Seed Shells.

The **table 4.18** below summarizes the mechanical test outputs for the concrete that was carried out during the study.

Table 4- 18: Mechanical test results for concrete

No.	Sample code	Material tests							
		Compressive Strength (Mpa)	**Flexural Strength (Mpa)**	**Splitting Tensile Strength (Mpa)**	**Thermal Conductivity (W/mK)**	**Modulus of Elasticity (Mpa)**	**Water Absorption (%)**	**Fire Resistance**	**Density (kg/m3)**
1.0	Specifications	> 25	> 2.6	> 2.2	2.7		< 3		< 2200
2.0	100% of Coarse Aggregates	26.4	6.8	1.9	2.7	24750	2.5		2367
3.0	25% of Quarter Seed Shells	25.2	2.9	1.9	1.9	21034	3.6		2219
4.0	50% of Quarter Seed Shells	25.1	2.3	1.8	1.6	15750	4.2		2112
5.0	75% of Quarter Seed Shells	23.3	2.2	1.7	1.1	12263	5.9		1982
6.0	100% of Quarter Seed Shells	21.6	0.6	1.4	1.1	8100	5.5		1834
7.0	25% of Half Seed Shells	22.3	1	1.5	1.1	13118	4.1		2255
8.0	50% of Half Seed Shells	13	0.5	1.1	1.9	6094	6.8		2004
9.0	75% of Half Seed Shells	6.9	0.4	0.7	0.8	3569	8.4		1876
10.0	100% of Half Seed Shells	4.1	0.3	0.5	0.9	2085	10.8		1641

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to investigate the performance of kukui seed shell size and replacement percentage as lightweight concrete. This was achieved by replacing coarse aggregates with Kukui Seed Shells (Half Seed Shells and Quarter Seed Shells) in 0% , 25% , 50%, 75% and 100% replacement quantities. Different mechanical and physical tests were done on the kukui seeds and the different concrete mixes they were put in.

It was determined that the shells have thin longitudinally arranged grains in its microstructure. Additionally, it was determined that the kukui seed shells fall under the category of Light Weight Aggregates and they had good Aggregate Impact values (AIV), Aggregate Crushing Values (ACV), Los Angeles Abrasion Values (LAA) and Soundness values due to the presence of Lignin and Cellulose in the seed shell.

It was concluded that there was an effect on the mechanical properties of the concrete. As the percentages of kukui seeds (Half Seed Shells and Quarter Seed Shells) increased in the concrete, there was a reduction in density the Compressive strength, Flexural Strength, Modulus of Elasticity and Splitting Tensile Strength.

It was determined that there was an effect on the Water Absorption, Thermal Conductivity and Fire resistance performance of the concrete. As the percentages of kukui seeds (Half Seed Shells and Quarter Seed Shells) increased, there was a reduction in Thermal Conductivity and an increase in the Water Absorption values. The concrete cube samples failed the Fire Resistance tests.

Furthermore, it was determined that the Quarter Seed Shell concrete performed better than the Half Seed Shell under serviceability performance. The Quarter seed shell concrete needed more force and could resist more Combined Stresses as opposed to the Half Seed Shell concrete. This was determined after analysis of ANSYS results.

Generally, the Quarter Seed Shell concrete performed better than the Half Seed Shell concrete.

5.2 Recommendations

For usable Concrete, the author recommends concrete that has 50% of the Quarter Seed Kukui Shells because of its good compressive strength (25.1MPa), good thermal conductivity properties (1.6W/mK) and low density (2,112kg/m3). Additional research should be carried out to find out how to improve on its water (4.2%), Splitting tensile (1.8MPa) and Flexural strength (2.3MPa) properties. The seeds should be properly soaked for more than 8 hours before mixing so that they are properly hydrated and hence won't affect the designed water: cement ratio.

5.3 Limitations of the study

i. The study was limited to a maximum aggregate size of 20mm which is recommended for reinforced concrete. **(CITE)**
ii. The study was limited to short term effects of kukui seed shells in concrete. It excludes studies related to long term effect of the seed shells in concrete. Examples of long-term effects include Creep and Shrinkage which are not covered in this study.
iii. The study was limited to concrete grade of C25. I do not consider effects of the kukui seed shells on other grades of concrete.

iv. This study has not considered the economic aspect of using the kukui seed shells due to lack of data to aid in assessing cost.

Kukui seed shell contribution to sustainable construction in Uganda

a. Using kukui seed shells support the use of local and renewable material
b. Using kukui seed shells promotes environmental conservation since there is re-use and re-purposing of the shell waste.
c. The use of kukui seed shells, which are Organic light weight aggregates, reduce the overall self-weight of a structure which reduces on the need for complex foundations to support the structure.
d. Kukui seed shell extraction and production process has a positive impact to the livelihood of the community taking part in the process by provision of employment and improved innovation skills in terms of re-using of this waste.
e. There is still more research that can be carried out on the kukui seed shells and their effects on concrete. Continued research can improve on the product and aid in finding solutions to help enhance areas where the product didn't perform as expected.

Possible applications of kukui seed shell concrete:

1. **Lightweight concrete applications:** Due to its low density it can be used to make partitioning walls, filler blocks and precast items like walkway pavers and slabs.
2. **Thermal and acoustic insulation:** Due to its good thermal conductivity values, it can be used to insulate roof screed and provide both acoustic and insulation internal wall panels.

3. **Medium strength structural elements:** With addition of some admixtures to improve on some properties like flexural strength, the concrete can be used in some structural elements like lintels.
4. **Sustainable and Eco-friendly construction**: Since we are utilizing waste, it can be used for different green building projects which are designed and built to minimize environmental impact by reduction of carbon footprint.
5. **Internal curing applications:** In areas where mass concrete is used, the internal curing properties reduce cracking and improve performance of concrete exposed to early-age thermal gradients

Other areas of study that should be explored include:

1. The feasibility of whether the kukui seed shells can be used in the transportation sector to make an appropriate wearing coarse material when mixed with bitumen.
2. Water Absorption treatment for highly absorptive aggregates (Light Weight Aggregates)
3. Reduction of air voids in Quarter Kukui Seed Shell concrete
4. The evaluation of the use of Eighth Kukui Seed Shells as a material replacement for Fine Aggregates
5. The effect of the use of CEM 1 cement on the properties of concrete that uses kukui seeds shells as coarse aggregates
6. Design an appropriate crushing mechanism for crushing the kukui seed shells that reduces on the flakiness of the shells
7. Fire resistance of Organic Light weight Aggregate

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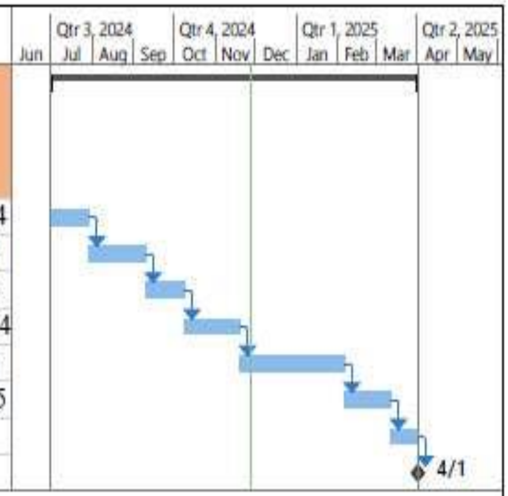
CHAPTER 7: APPENDICES

Appendix A.1: Work Program

ID	Task Mode	Task Name	Duration	Start	Finish
1		**KUKUI SEED SHELLS AS REPLACEMENT MATERIAL FOR COARSE AGGREGATES IN LIGHT WEIGHT CONCRETE**	**197 days**	**Mon 7/1/24**	**Tue 4/1/25**
2		Inception	21 days	Mon 7/1/24	Mon 7/29/24
3		Data Collection	30 days	Tue 7/30/24	Mon 9/9/24
4		Material Collection	21 days	Tue 9/10/24	Tue 10/8/24
5		Construction of experimental systems	30 days	Wed 10/9/2	Tue 11/19/24
6		Laboratory tests	56 days	Wed 11/20/	Wed 2/5/25
7		Analysis of results	25 days	Thu 2/6/25	Wed 3/12/25
8		Compiling report	14 days	Thu 3/13/25	Tue 4/1/25
9		Presentation	0 days	Tue 4/1/25	Tue 4/1/25



Appendix A.2: Kukui seed Shell Tests

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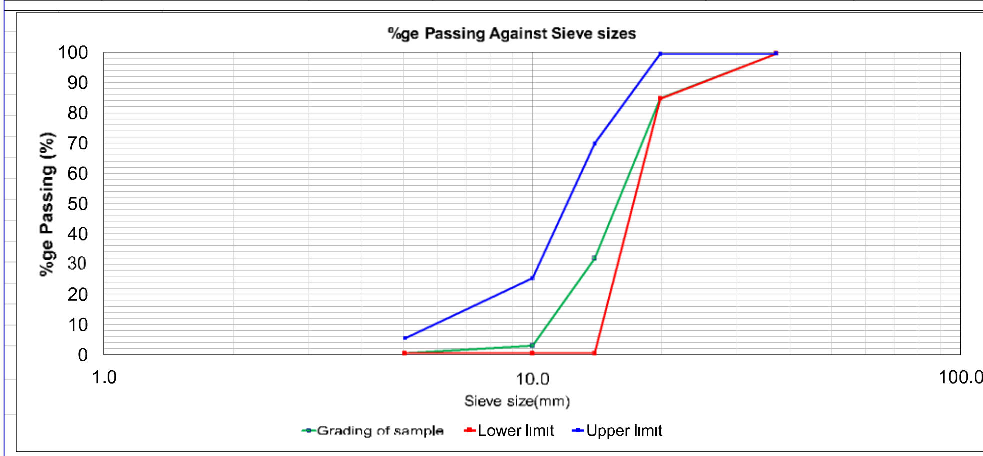
SIEVE ANALYSIS OF COARSE AGGREGATES

REF : BS 812 : Part 103.1: 1985

PROJECT : Evaluating mechanical properties of kukui seed shells and coarse aggregates

Sample Reference : G/CA/01			**Sampling Date:** 11/02/2025	
Description : Single Sized Aggregates (20mm)			**Testing Date:** 12/02/2025	
Source : Ntinda			**Technician :** Ancel	
Dry Mass before washing, M_1	2226.3	g	Dry mass after washing	2226.3
Initial dry weight, M_3	2217.3	g	$M_1 - M_2$	0.0

sieve size (mm)	Aperture size (mm)	Mass Retained (g)	%ge retained (%)	%ge passing (%)	Specification Limits BS 882 : 1992 : TABLE 3	
					Lower limit	Upper limit
37.5	37.5	0.0	0.0	100	**100**	**100**
20.0	20.0	330.2	14.9	85	**85**	**100**
14.0	14.0	1187.5	53.6	32	**0**	**70**
10.0	10.0	645.6	29.1	2	**0**	**25**
5.0	5.0	54.0	2.4	0	**0**	**5**



Tested by: Ancel

Checked by: Caleb

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CONCRETE LABORATORY

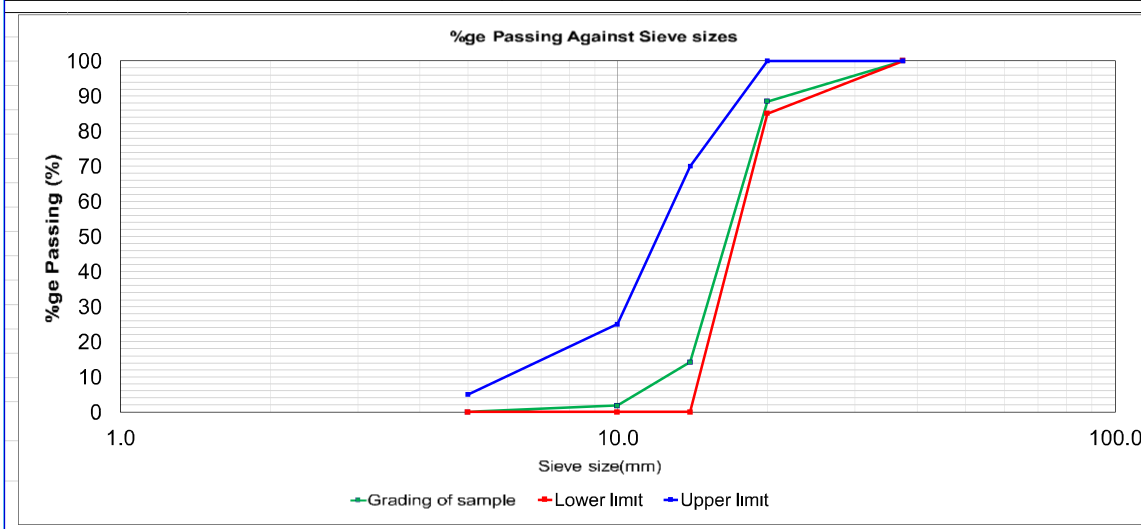
SIEVE ANALYSIS OF HALF SEED SHELLS

REF : BS 812 : Part 103.1: 1985

PROJECT : Evaluating mechanical properties of kukui seed shells and coarse aggregates

Sample Reference : G/HSS/01			**Sampling Date:** 11/02/2025	
Description : Single Sized Aggregates (20mm)			**Testing Date:** 12/02/2025	
Source : Rushogashoga (Sheema district)			**Technician :** Ancel	
Dry Mass before washing, M_1	334.0	g	Dry mass after washing	334.0
Initial dry weight, M_3	304.0	g	$M_1 - M_2$	0.0

sieve size (mm)	Aperture size (mm)	Mass Retained (g)	%ge retained (%)	%ge passing (%)	**Specification Limits BS 882 : 1992 : TABLE 3**	
					Lower limit	Upper limit
37.5	37.5	0.0	0.0	100	**100**	**100**
20.0	20.0	35.1	11.5	88	**85**	**100**
14.0	14.0	226.0	74.3	14	**0**	**70**
10.0	10.0	37.6	12.4	2	**0**	**25**
5.0	5.0	5.3	1.7	0	**0**	**5**



Tested by: Ancel

Checked by: Caleb

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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONCRETE LABORATORY

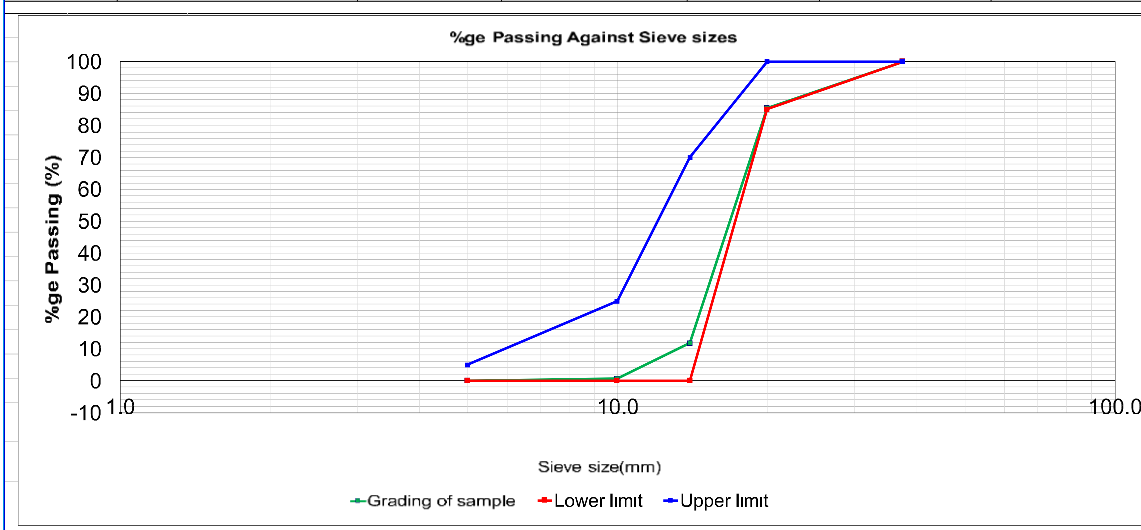
SIEVE ANALYSIS OF HALF SEED SHELLS

REF : BS 812 : Part 103.1: 1985

PROJECT : Evaluating mechanical properties of kukui seed shells and coarse aggregates

Sample Reference : G/HSS/02			**Sampling Date:** 11/02/2025	
Description : Single Sized Aggregates (20mm)			**Testing Date:** 12/02/2025	
Source : Rushogashoga (Sheema district)			**Technician :** Ancel	
Dry Mass before washing, M_1	323.0	g	Dry mass after washing	323.0
Initial dry weight, M_3	323.0	g	M_1 - M_2	0.0

sieve size (mm)	Aperture size (mm)	Mass Retained (g)	%ge retained (%)	%ge passing (%)	Specification Limits BS 882 : 1992 : TABLE 3	
					Lower limit	Upper limit
37.5	37.5	0.0	0.0	100	**100**	**100**
20.0	20.0	46.8	14.5	86	**85**	**100**
14.0	14.0	238.3	73.8	12	**0**	**70**
10.0	10.0	35.7	11.1	1	**0**	**25**
5.0	5.0	2.2	0.7	0	**0**	**5**



Tested by: Ancel

Checked by: Caleb

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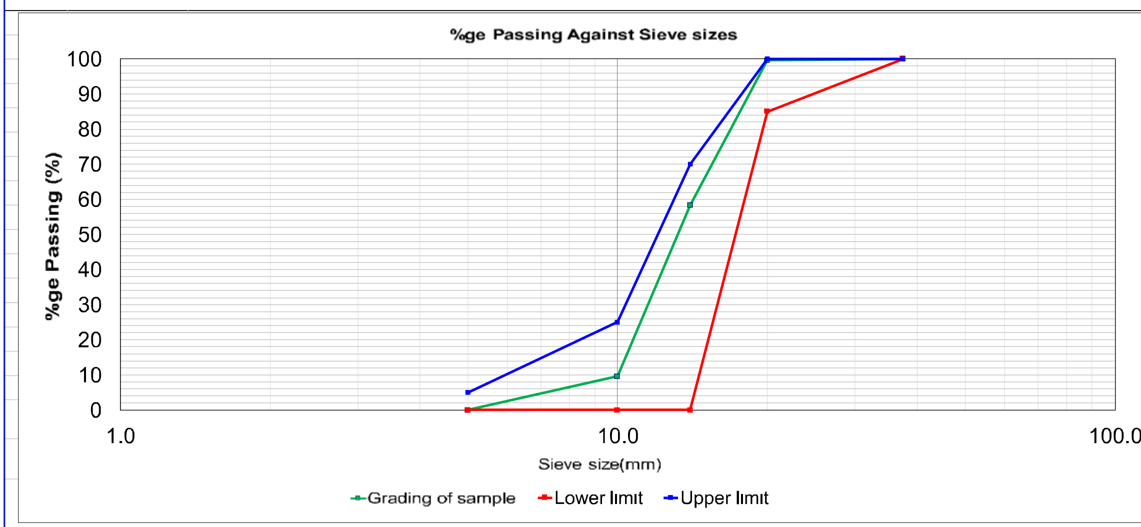
SIEVE ANALYSIS OF QUARTER SEED SHELLS

REF : BS 812 : Part 103.1: 1985

PROJECT : Evaluating mechanical properties of kukui seed shells and coarse aggregates

Sample Reference : G/QSS/01			**Sampling Date:** 11/02/2025	
Description : Single Sized Aggregate (20mm)			**Testing Date:** 12/02/2025	
Source : Rushogashoga (Sheema district)			**Technician :** Ancel	
Dry Mass before washing, M_1	485.1	g	Dry mass after washing	485.1
Initial dry weight, M_3	615.8	g	$M_1 - M_2$	0.0

sieve size (mm)	Aperture size (mm)	Mass Retained (g)	%ge retained (%)	%ge passing (%)	Specification Limits BS 882 : 1992 : TABLE 3	
					Lower limit	Upper limit
37.5	37.5	0.0	0.0	100	**100**	**100**
20.0	20.0	2.3	0.4	100	**85**	**100**
14.0	14.0	254.8	41.4	58	**0**	**70**
10.0	10.0	300.0	48.7	10	**0**	**25**
5.0	5.0	58.7	9.5	0	**0**	**5**



Tested by: Ancel

Checked by: Caleb

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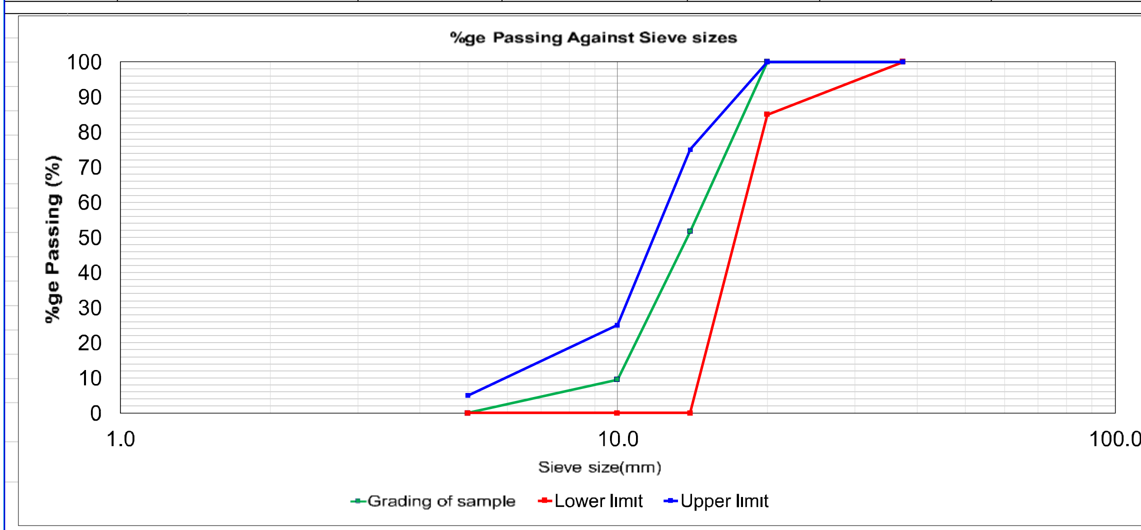
SIEVE ANALYSIS OF QUARTER SEED SHELLS

REF : BS 812 : Part 103.1: 1985

PROJECT : Evaluating mechanical properties of kukui seed shells and coarse aggregates

Sample Reference : G/QSS/02				**Sampling Date:** 11/02/2025		
Description : Singlw Sized Aggregate				**Testing Date:** 12/02/2025		
Source : Rushogashoga (Sheema district)				**Technician :** Ancel		
Dry Mass before washing, M_1		528.3	g	Dry mass after washing		528.3
Initial dry weight, M_3		653.8	g	M_1 - M_2		0.0

sieve size (mm)	Aperture size (mm)	Mass Retained (g)	%ge retained (%)	%ge passing (%)	**Specification Limits** **BS 882 : 1992 : TABLE 3** Lower limit	Upper limit
37.5	37.5	0.0	0.0	100	**100**	**100**
20.0	20.0	0.0	0.0	100	**85**	**100**
14.0	14.0	316.2	48.4	52	**0**	**75**
10.0	10.0	275.8	42.2	9	**0**	**25**
5.0	5.0	61.8	9.5	0	**0**	**5**



Tested by: Ancel

Checked by: Caleb

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SIEVE ANALYSIS OF SAND

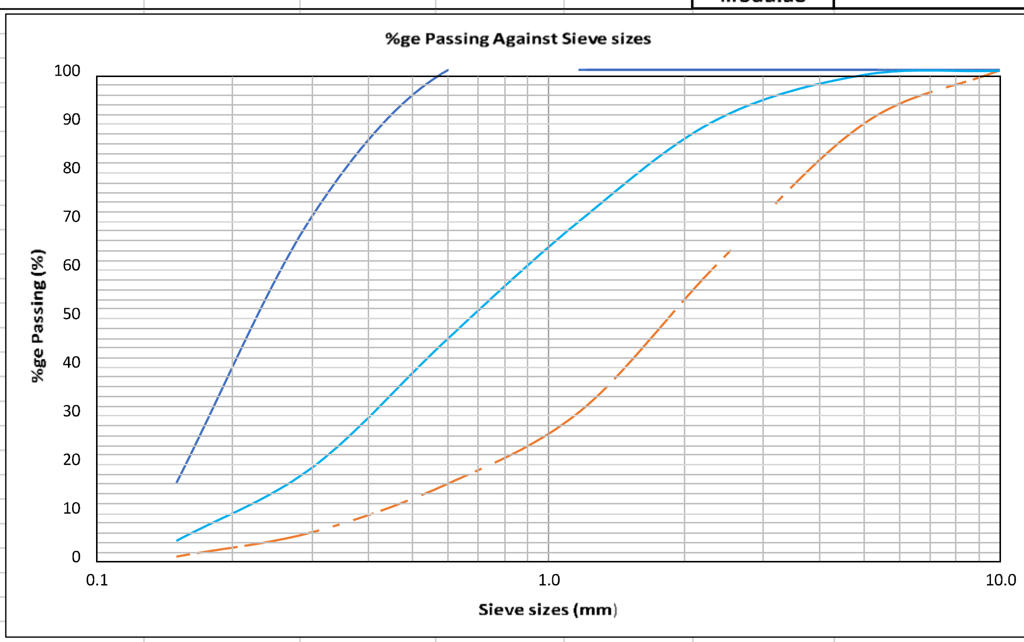
REF: BS 812 : 103.1

Sample Reference	: G/FA/01	**Sampling Date**	: 01/02/2025
Location	: Kyambogo	**Testing Date**	: 03/02/2025
Source	: Ntında	**Technician**	: Ancel
Sample Description	: Greyish fine sand		

Project : Evaluating mechanical properties of fine sand to be used in kukui seed shells concrete

Initial wt before washing :	(g) A =	A - B =	0.0
Dry wt after washing :	(g) B =	Initial Dry Weight :	1025.4

Sieve sizes (mm)	Mass Retained (g)	%ge mass Retained (%)	Cumulative %ge Retained (%)	%ge Passing (%)	BS 882 : 1992 (TABLE 4) C, M or F	
10.0	0.0	0.0	0.0	100	100	100
5.0	8.6	0.8	0.8	99	89	100
2.36	94.6	9.2	10.1	90	60	100
1.18	211.5	20.6	30.7	69	30	100
0.600	**249.4**	**24.3**	**55.0**	**45**	**15**	**100**
0.300	273.0	26.6	81.6	18	5	70
0.150	155.0	15.1	96.8	3	0	15
< 0.150	31.9	3.1	99.9			
					Fineness Modulus	**2.75**



Tested By : Ancel

Checked By : Caleb

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AVERANGE IMPACT VALUE (AIV) TEST

Sample Reference : AIV/QSS/01			
Sampling Date :	**Technician :** Ancel		
Sample Description : Single Sized Aggregates (20mm)	**Material Source :** Rushogashog		
Sample Condition : Dry	**Materials Size :** 20mm Single sized		
Sample Number			
Mass of sample (g)			
Mass of portion ret			
ss of portion p			
Mass of retained and passing 2 36 mm sieve (g)			
AVERAGE VALUE			
Tested by : Ancel			
Checked by : Caleb			
	The Number of Blows for Soaked		

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AVERANGE IM ACT VALUE (AIV) TEST

i g 2 36 mm			

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AVERANGE IMPACT VALUE (

i g 2 36 mm			
i g 2 36 mm			
AVERAGE VALUE			

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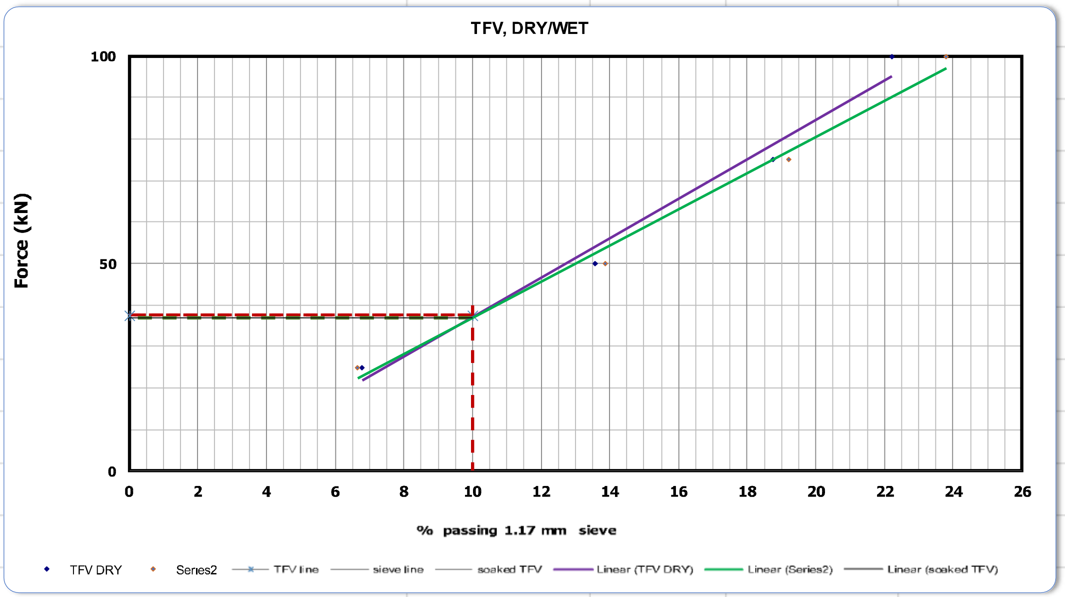
TEN PERCENT FINES VALUE (TFV) TEST
BS 812 - 111

Sample Reference : TFV/CA/01		Sampling Date	11/2/2025
Location : Kyambogo		Testing Date	14/02/2025
Sample Description : 20mm Single Sized Aggregates		Material Source	Ntinda

Sample Condition: DRY		Materials Size:	10-6.3 mm	
Force (kN)	100	75	50	25
Mass of sample (g)	307.9	308.0	308.5	308.3
Mass of portion retained on 1.17 mm sieve (g)	239.5	250.3	266.6	287.4
Mass of portion passing 1.17 mm sieve (g)	68.4	57.7	41.9	20.9
Mass of retained and passing 1.17 mm sieve (g)	307.9	308.0	308.5	308.3
% fines passing 1.17 mm sieve	22.2	18.7	13.6	6.8
Sample Condition: SOAKED		Materials Size:	10-6.3 mm	
Force (kN)	100	75	50	25
Mass of sample (g)	292.1	292.0	291.4	291.8
Mass of portion retained on 1.17 mm sieve (g)	222.6	235.9	251.0	272.4
Mass of portion passing 1.17 mm sieve (g)	69.5	56.1	40.4	19.4
Mass of retained and passing 1.17 mm sieve (g)	292.1	292.0	291.4	291.8
% fines passing 1.17 mm sieve	23.8	19.2	13.9	6.6



TFV Value DRY, kN	37.5	Soaked/Dry ratio	99%
TFV Value SOAKED, kN	37.0	ACV value , %	22.2

Technician : Ancel	**Technician :**
Checked by : Caleb	**Checked by :**
Date: 14/02/2025	**Date:**

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CONCRETE LA

SPECIFIC GRAVITY & WATER A

REF : BS 812: PART 2: 1975

Sample Reference : G_S/CA/01	**Sample Description :** Coarse			
Location : Kyambogo	**Technician :** Ancel			
Sampling Date : 11/02/2025	**Material Source :**			
Testing Date : 13/02/2025				
Pyknometer No				
Mass of saturated surface dry aggregate in air g				
Mass of Pyknometer + sample filled with water g				
Mass of Pyknometer filled with water only g				
Mass of oven dry aggregate				
Relative density on an oven				
Relative Density on a saturated and surface dry basis				
Water Absorption				
Wire Basket				
Mass of saturated surface dry aggregate in air g				
Mass of basket + sample in water g				
Mass of empty basket in water				
Mass of oven dry aggregate in air g				
Relative density on an oven dry basis				
Relative Density on a saturated and surface				
Water Absorption				
Tested by : Ancel				
Checked by : Caleb				
Remarks :				

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CONCRETE LA

SPECIFIC GRAVITY & WATER ABSORPTION (FINE AGGREGATES)

REF : BS 812: PART 2: 1975

mple Reference : G_S/FA/01	**Sample Description :** Greyish fine Sand			
Location : Kyambogo	**Technician :** Ancel			
mpling Date : 12/02/2025	**Material Source :**			
Testing Date : 13/02/2025				
Pyknometer No				
Mass of saturated surface				
Mass of Pyknometer + sample filled with water g				
Mass of Pyknometer filled with water only g				
Mass of oven dry aggregate in air g				
Relative density on an oven dry basis				
Density on a saturated and surface				
Apparent Rel				
Water Absorption				
Wire Basket				
ss of saturated surface dry				
Mass of basket + sample in water g				
Mass of empty basket in water				
Mass of oven dry aggregate in air g				
Relative density on an oven dry basis				
Relative Density on a saturated and surface dry basis				
Water Absorption				
Tested by : Ancel				
Checked by : Caleb				
Remarks :				

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Flakiness Index (FI)

Sample Reference	**Testing Date**
Sampling D	
Sample Description	**Material Source :**
Flakiness Index (FI)	

		Total Mass	% age Fraction	retained (g)		
Sub total						
Excluding % age Fraction <5%						
kiness Index (FI)						

Tested by : *Ancel*

Checked by : Caleb

Remarks :

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CONCRETE LABORATORY

Flakiness Index (FI)

Sample Reference	**Testing Date**
Sampling D	
Sample Description	**Material Source :**

Flakiness Index (FI)

		Total Mass	% age Fraction	retained (g)		
Sub total						
Excluding % age Fraction <5%						
kiness Index (FI)						

Tested by : *Ancel*

Checked by : Caleb

Remarks :

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CONCRETE LABORATORY

SILT, CLAY AND DUST CONTENT IN SAND

REF: AASHTO T 11

Sample Reference :	S/FA/01	**Sampling Date :**	11/02/2025
Location :	Kyambogo	**Testing Date :**	14/02/2025
Source :	Ntinda	**Technician :**	Ancel

Sample Description : Greyish fine sand

Initial dry weight before washing, A	(g)	964.5	1034.5
Dry weight after washing on BS sieve 0.075mm, B	(g)	936.5	1003.3
Weight passing BS test sieve 0.075mm A - B	(g)	28.0	31.2
Percentage passing BS test sieve $\frac{A-B}{A} * 100$	(%)	2.90	3.02
Average Silt Content	(%)	**3.0**	

Tested by : Ancel

Checked by :

Remarks :

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CONCRETE LABORATORY

Evaluating the mechanical performance of kukui seed shells as a coarse aggregate in light weight aggregate c nerete

(A

Aggr gat

f Aggregat

638 20

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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING						
CONCRETE LABORATORY						
		Evaluating th aggr gate concr t				
Aggregate Crushing Value (ACV)						
		Wt of Container	Wt of Aggregates	Wt of sample passg + Container	Wt of Sample p ssg 2 36mm Sieve	
		830 00				
		830 00				

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CONCRETE LABORATORY			
LOS ANGELES ABRASION VALUE (LAAV)ASTM C535			
		Sampling Date :	
Location/Source:		Testing Date :	26 03 2025
Sample Description:			
ggregate in m chine (A)			
Wt retained on the 5 0 mm sieve (B)			
Los Angeles Abr sion Value= (B A)/A x100			

BR SION V LUE (L AV) STM C535

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	Evaluating th aggregate c ncrete					
Soundness Test						
	Percentage l weight	l weight (kg)	First immersion			
			399 20			

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CONCRETE LABORATORY

	Ev lu ting the mechanic l perf rmance aggregate c ncrete					
Soundness Test						
	Percentage loss in weight		First immersion	Second Immersi		S undness

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CONCRETE LABORATORY						
		Evaluating the mechanical performance of kukui se d shells as a coarse aggregate in light weight aggregate concrete				
Soundness T						
	Percentage loss in w ight	l weight (kg)	First immersion			Soundness
			384 30			
			3 925%	3 925%		

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CONCRETE LA

SPECIFIC GRAVITY & WATER ABSORPTION (FINE AGGREGATES)

REF : BS 812: PART 2: 1975

mple Reference : G_S/FA/01	**Sample Description :** Greyish fine Sand			
Location : Kyambogo	**Technician :** Ancel			
mpling Date : 12/02/2025	**Material Source :**			
Testing Date : 13/02/2025				
Pyknometer No				
Mass of saturated surface				
Mass of Pyknometer + sample filled with water g				
Mass of Pyknometer filled with water only g				
Mass of oven dry aggregate in air g				
Relative density on an oven dry basis				
Density on a saturated and surface				
Apparent Rel				
Water Absorption				
Wire Basket				
ss of saturated surface dry				
Mass of basket + sample in water g				
Mass of empty basket in water				
Mass of oven dry aggregate in air g				
Relative density on an oven dry basis				
Relative Density on a saturated and surface dry basis				
Water Absorption				
Tested by : Ancel				
Checked by : Caleb				
Remarks :				

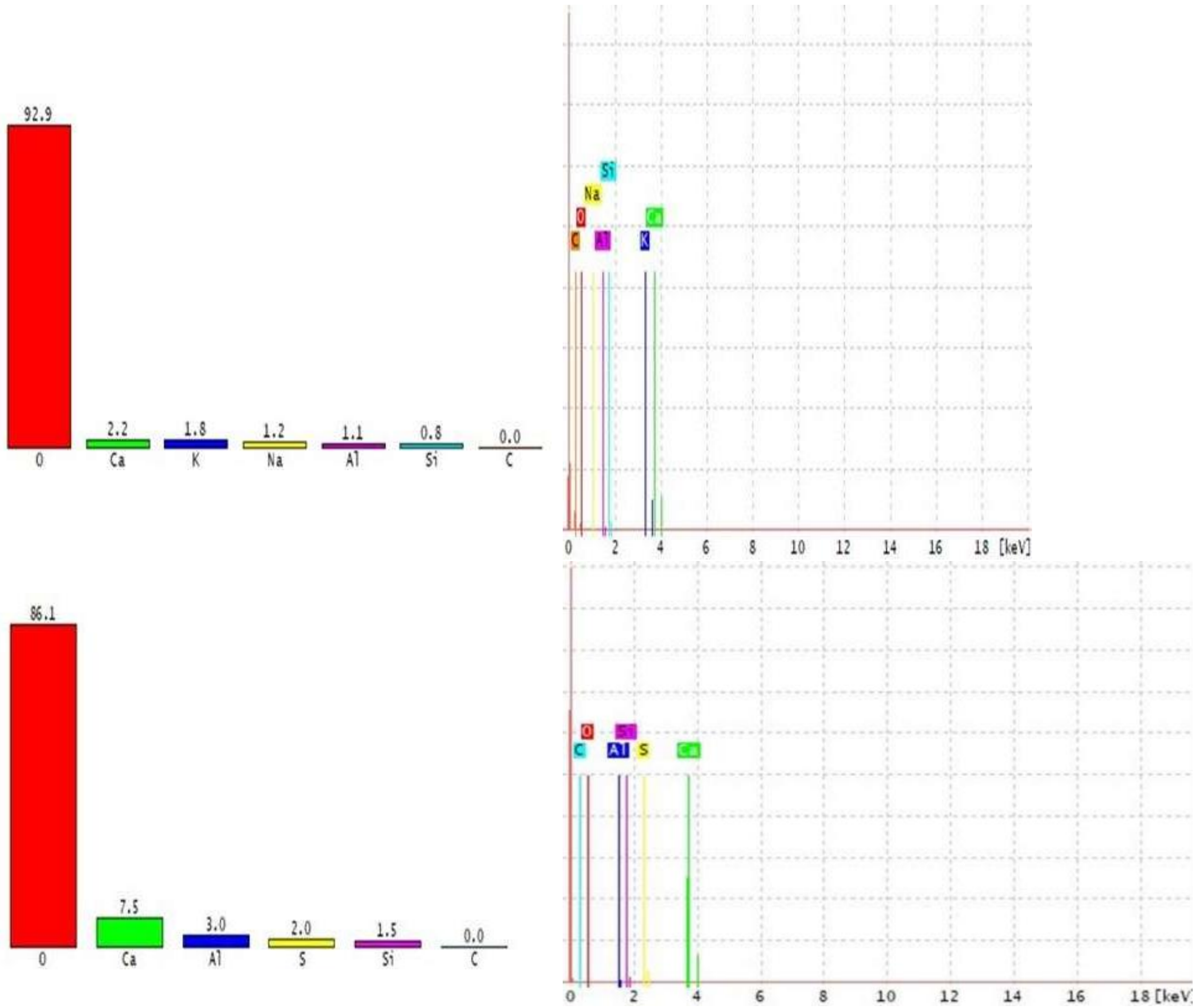

Fig. A.2.1 : Chemical composition from SEM

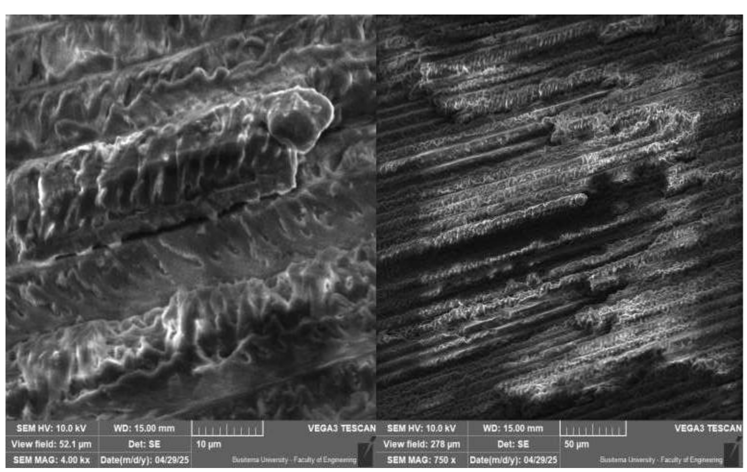

Fig. A.2.2: Microstructure from SEM

Appendix A.3 : Mix design

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P.O. BOX 1, Kyambogo Uganda

HIGHWAYS/MATERIALS LABORATORY

DETAILS OF PROPOSED MIX DESIGN

FOR

BAGOMBEKA ANCEL

CONCRETE CLASS 25/20

Trial Mix N^{o} 1

February, 2025

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HIGHWAYS/MATERIALS LABORATORY			
Topic : Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete			
Client: Bagombeka Ancel			
Class of Concrete :	25		
Design Date	23-Feb-25		
Mix Design Requirements (MoWHC - Series 6000)	Slump Limits	30-60	mm
	Nominal Max size of agg.	20	mm
	Characteristic Strength on 28 days (cube)	25	N/mm^2
	Trial mix mean Target Strength (28 days) Characteristic Strength + Current Margin	25 + 13 = 38	N/mm^2
	Max Free water to Cement ratio	0.50	
	Min Cement content	330	kg/m^3
Ingredients	Cement manufacture	Tororo Cement	
	Type of cement	CEM II, 32.5N	
	Coarse aggegates	Ntinda	
	Fine aggegates	Lwera	
Final Design Data	Cement content for mix design	380	kg/m^3
	7^{th} day average Cube compressive strength		Mpas
	28^{th} day average Cube compressive strength		Mpas
	Observed Slump		mm
	Water/Cement Ratio	0.50	

DESIGNED BY : Caleb	**CHECKED BY :**
DATE : 23rd February 2025	**DATE :**

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Topic : Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete

Client: Bagombeka Ancel

Class：	25			
Design Date	23-Feb-25			
Mix Design Data (Lab test data)	Specific gravity of Cement	3000	(kg/m^3)	
	Bulk Specific gravity, SSD (20/5)mm	2637	(kg/m^3)	
	Bulk Specific gravity, SSD (5/0)mm	2598	(kg/m^3)	
	Loose Unit weight, 20/5		(kg/m^3)	
	Loose Unit weight, 5/0		(kg/m^3)	
	Water Absorion of aggr. (20/5)	0.233	%	
	Water Absorion of aggr. (5/0)	2.438	%	

Batching weight per cum on apparent specific gravity and corrected weight	Absolute Vol. of cement	380/3000 =	0.127	m^3
	Water	190/1000 =	0.190	m^3
	Entrapped air, considering 2%	=	0.020	m^3
	So total volume of paste	=	0.337	m^3
	Therefore,soild volume of aggregate	=	0.663	m^3
	Blending portion of 14/5 ,5/0	=	63%	37%
	Therefore,volume of Coarse aggregate 14/5	=	0.418	m^3
	Volume of fine aggregate 5/0	=	0.245	m^3

	Material	Volume m^3	Density kg/m^3	Batch Weight in kg per m^3 of concrete	Corrected batch Weight in kg per m^3 of concrete
Batching weight per cum of concrete on SSD condition and corrected weight	Cement	0.127	3000	380.0	380.0
	Water	0.190	1000	190.0	208.1
	Coarse, crushed agg.(14-5)	0.418	2637	1102.0	1099.4
	Fine, Uncrushed agg.(5-0)	0.245	2598	637.6	622.1
	Voids	0.020			
	Total Wt.	1.00		2310	2310

DESIGNED BY : Caleb	**CHECKED BY :**
DATE : 23rd February 2025	**DATE :**

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Topic : Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete (Compressive Strength)

Client: Bagombeka Ancel

Class ： 25

Design Date 23rd February 2025

Batching weight per cum of concrete on SSD condition and corrected weight	Material	Volume m^3	Density kg/m^3	Weight in kg per m^3 of concrete	Corrected Weight in kg per m^3 of concrete
	Cement	0.127	3000	380.0	380.0
	Water	0.190	1000	190.0	210.2
	Coarse, crushed agg.(20-5)	0.418	2637	1102.0	1100.5
	Fine, Uncrushed agg.(5-0)	0.245	2598	637.6	618.9
	Void	0.020			
	Total Wt.	1.00		2310	2310

Lab batch for concrete cubes 6 cubes each 10 kg total fresh concrete is 6*10=60kg.	Materials	Weight in kg for lab batch	Final lab mix proportion, kg
	Cement	9.87	**9.87**
	Water	4.94	**5.46**
	Coarse aggregate (20-5) mm	28.63	**28.59**
	Fine aggregate (5-0) mm	16.56	**16.08**
	Total Wt.	60.0	60.0

DESIGNED BY : Caleb	**CHECKED BY :**
DATE : 23rd February 2025	**DATE :**

% Replacement (%)	Mass of Coarse Aggregate (kg)	Volume of Coarse Aggregate (m^3)	Mass of Shell (kg)	Volume of Shell (m^3)		
0	31.47	0.01193	0.00	0.00000		
25	23.60	0.00895	4.16	0.002984	Specific Gravity of Kukui Quarter size shells	1394
50	15.74	0.00597	8.32	0.005967	Specific Gravity of Coarse Aggregates	2637
75	7.87	0.00298	12.48	0.008951		
100	0.00	0.00000	16.64	0.011934		
Total Needed	**78.68**		**41.59**			

% Replacement (%)	Mass of Coarse Aggregate (kg)	Volume of Coarse Aggregate (m^3)	Mass of Shell (kg)	Volume of Shell (m^3)		
0	28.59	0.01084	0.00	0.00000		
25	21.44	0.00813	3.85	0.002710	Specific Gravity of Kukui Half size shells	1421
50	14.29	0.00542	7.70	0.005421	Specific Gravity of Coarse Aggregates	2637
75	7.15	0.00271	11.55	0.008131		
100	0.00	0.00000	15.41	0.010841		
Total Needed	**71.47**		**38.51**			

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Topic : Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete (Split Tensile Strength)

Client: Bagombeka Ancel

Class : 25

Design Date 23rd February 2025

Batching weight per cum of concrete on SSD condition and corrected weight	Material	Volume m^3	Density kg/m^3	Weight in kg per m^3 of concrete	Corrected Weight in kg per m^3 of concrete
	Cement	0.127	3000	380.0	380.0
	Water	0.190	1000	190.0	210.2
	Coarse, crushed agg.(20-5)	0.418	2637	1102.0	1100.5
	Fine, Uncrushed agg.(5-0)	0.245	2598	637.6	618.9
	Void	0.020			
	Total Wt.	1.00		2310	2310

Lab batch for concrete cylinder 6 cylinders each 5 kg total fresh concrete is 6*5=30kg.	Materials	Weight in kg for lab batch	Final lab mix proportion, kg
	Cement	4.94	4.94
	Water	2.47	2.73
	Coarse aggregate (20-5) mm	14.31	14.29
	Fine aggregate (5-0) mm	8.28	8.04
	Total Wt.	30.0	30.0

DESIGNED BY : Caleb	**CHECKED BY :**
DATE : 23rd February 2025	**DATE :**

% Replacement (%)	Mass of Coarse Aggregate (kg)	Volume of Coarse Aggregate (m^3)	Mass of Shell (kg)	Volume of Shell (m^3)
0	14.29	0.00542	0.00	0.00000
25	10.72	0.00406	1.89	0.001355
50	7.15	0.00271	3.78	0.002710
75	3.57	0.00135	5.67	0.004064
100	0.00	0.00000	7.55	0.005419
Total Needed	**35.73**		**18.89**	

Specific Gravity of Kukui Quarter size shells	**1394**
Specific Gravity of Coarse Aggregates	**2637**

% Replacement (%)	Mass of Coarse Aggregate (kg)	Volume of Coarse Aggregate (m^3)	Mass of Shell (kg)	Volume of Shell (m^3)
0	14.29	0.00542	0.00	0.00000
25	10.72	0.00406	1.93	0.001355
50	7.15	0.00271	3.85	0.002710
75	3.57	0.00135	5.78	0.004064
100	0.00	0.00000	7.70	0.005419
Total Needed	**35.73**		**19.25**	

Specific Gravity of Kukui Half size shells	**1421**
Specific Gravity of Coarse Aggregates	**2637**

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HIGHWAYS/MATERIALS LABORATORY

Topic : Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete (Flexural Strength)

Client: Bagombeka Ancel

Class： 25

Design Date 23rd February 2025

Batching weight per cum of concrete on SSD condition and corrected weight	Material	Volume m^3	Density kg/m^3	Weight in kg per m^3 of concrete	Corrected Weight in kg per m^3 of concrete
	Cement	0.127	3000	380.0	380.0
	Water	0.190	1000	190.0	210.2
	Coarse, crushed agg.(20-5)	0.418	2637	1102.0	1100.5
	Fine, Uncrushed agg.(5-0)	0.245	2598	637.6	618.9
	Void	0.020			
	Total Wt.	1.00		2310	2310

Lab batch for concrete Beams, 3 Beams each 40 kg total fresh concrete is 3*40=120kg.	Materials	Weight in kg for lab batch	Final lab mix proportion, kg
	Cement	19.74	19.74
	Water	9.87	10.92
	Coarse aggregate (20-5) mm	57.26	57.18
	Fine aggregate (5-0) mm	33.13	32.16
	Total Wt.	120.0	120.0

DESIGNED BY : Caleb	**CHECKED BY :**
DATE : 23rd February 2025	**DATE :**

% Replacement (%)	Mass of Coarse Aggregate (kg)	Volume of Coarse Aggregate (m^3)	Mass of Shell (kg)	Volume of Shell (m^3)		
0	57.18	0.02168	0.00	0.00000		
25	42.89	0.01626	7.70	0.005421	Specific Gravity of Kukui Half size shells	**1421**
50	28.59	0.01084	15.41	0.010842	Specific Gravity of Coarse Aggregates	**2637**
75	14.30	0.00542	23.11	0.016263		
100	0.00	0.00000	30.81	0.021684		
Total Needed	**142.95**		**77.03**			

Appendix A.4: Hardened Concrete Tests

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CONCRETE LABORATORY

Compressive Strength of Concrete Cubes
BS 1881: Part 116: 1983

Coarse Agg. Source : Ntinda	Fine Agg. Source : Ntinda	Cement Type & Source : CEM II, 32.5N, Tororo Made
Technician : Ancel	Class of concrete : 25	Type of Concrete : Reinforced Concrete

COMPRESSIVE STRENGTH OF CONCRETE, MACHINE CRUSHED 20MM

Cube Ref No.	Date Casted	Date Tested	Specimen Size (mm)	Weight of cube in air (g)	Density (Kg/m^3)	Average density (Kg/m3)	Age (Days)	Max. Crushing Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
CS/CA/07/01	3/1/2025	3/10/2025	150 x 150 x 150	7872	2333	2340	7	510.4	22.7	23.3
CS/CA/07/02				7925	2348			537.3	23.9	
CS/CA/07/03				7892	2338			528.0	23.5	
CS/CA/28/01		3/31/2025		7959	2358	2367	28	598.4	26.6	26.4
CS/CA/28/02				8014	2375			590.2	26.2	
CS/CA/28/03				7993	2368			595.4	26.5	

COMPRESSIVE STRENGTH OF CONCRETE, 25% QUARTER SIZE SEED

CS/QSS/25/01	3/1/2025	3/10/2025	150 x 150 x 150	7389	2189	2195	7	422	18.8	19.7
CS/QSS/25/02				7439	2204			465	20.7	
CS/QSS/25/03				7401	2193			440	19.6	
CS/QSS/25/04		3/31/2025		7362	2181	2219	28	567.7	25.2	25.2
CS/QSS/25/05				7613	2256			565.4	25.1	
CS/QSS/25/06				7489	2219			570.4	25.4	

COMPRESSIVE STRENGTH OF CONCRETE, 50% QUARTER SIZE SHELL

CS/QSS/50/01	3/1/2025	3/10/2025	150 x 150 x 150	7158	2121	2103	7	432	19.2	19.9
CS/QSS/50/02				7029	2083			465	20.7	
CS/QSS/50/03				7104	2105			443	19.7	
CS/QSS/50/04		3/31/2025		7261	2151	2112	28	542.6	24.1	25.1
CS/QSS/50/05				6994	2072			587.7	26.1	
CS/QSS/50/06				7133	2113			566.3	25.2	

COMPRESSIVE STRENGTH OF CONCRETE, 75% QUARTER SIZE SHELL

CS/QSS/75/01	3/1/2025	3/10/2025	150 x 150 x 150	6578.9	1949	1927	7	437.6	19.4	19.7
CS/QSS/75/02				6441.0	1908			447.9	19.9	
CS/QSS/75/03				6489.5	1923			445.3	19.8	
CS/QSS/75/04		3/31/2025		6670.9	1977	1982	28	532.4	23.7	23.3
CS/QSS/75/05				6717.0	1990			519.5	23.1	
CS/QSS/75/06				6675.5	1978			520.8	23.1	

COMPRESSIVE STRENGTH OF CONCRETE, 100% QUARTER SIZE SHELL

CS/QSS/100/01	3/1/2025	3/10/2025	150 x 150 x 150	6197.6	1836	1840	7	407.5	18.1	18.7
CS/QSS/100/02				6229.5	1846			432.6	19.2	
CS/QSS/100/03				6200.9	1837			418.9	18.6	
CS/QSS/100/04		3/31/2025		6158.8	1825	1834	28	454.1	20.2	21.6
CS/QSS/100/05				6220.5	1843			517.9	23.0	
CS/QSS/100/06				6193.3	1835			485.3	21.6	

COMPRESSIVE STRENGTH OF CONCRETE, 25% HALF SIZE SHELL

CS/HSS/25/01	3/1/2025	3/10/2025	150 x 150 x 150	7398.0	2192	2225	7	391.1	17.4	18.4
CS/HSS/25/02				7634.1	2262			434.9	19.3	
CS/HSS/25/03				7498.4	2222			412.7	18.3	
CS/HSS/25/04		3/31/2025		7592.3	2250	2255	28	517.5	23.0	22.3
CS/HSS/25/05				7606.9	2254			486.3	21.6	
CS/HSS/25/06				7632.6	2262			499.8	22.2	

COMPRESSIVE STRENGTH OF CONCRETE, 50% HALF SIZE SHELL

CS/HSS/50/01	3/7/2025	3/14/2025	150 x 150 x 150	6908.9	2047	2017	7	268.3	11.9	11.3
CS/HSS/50/02				6708.9	1988			238.9	10.6	
CS/HSS/50/03				6801.1	2015			252.9	11.2	
CS/HSS/50/04		4/4/2025		6747.3	1999	2004	28	316.6	14.1	13.0
CS/HSS/50/05				6774.7	2007			269.6	12.0	
CS/HSS/50/06				6768.9	2006			292.2	13.0	

COMPRESSIVE STRENGTH OF CONCRETE, 75% HALF SIZE SHELL

CS/HSS/75/01	3/7/2025	3/14/2025	150 x 150 x 150	6246.7	1851	1838	7	147.3	6.5	6.4
CS/HSS/75/02				6167.1	1827			138.9	6.2	
CS/HSS/75/03				6199.3	1837			144.5	6.4	
CS/HSS/75/04		4/4/2025		6270.3	1858	1876	28	165.2	7.3	6.9
CS/HSS/75/05				6394.8	1895			147.5	6.6	
CS/HSS/75/06				6333.4	1877			152.8	6.8	

COMPRESSIVE STRENGTH OF CONCRETE, 100% HALFSIZE SHELL

CS/HSS/100/01	3/7/2025	3/14/2025	150 x 150 x 150	5347.1	1584	1650	7	74.8	3.3	3.8
CS/HSS/100/02				5787.7	1715			97.6	4.3	
CS/HSS/100/03				5568.3	1650			83.9	3.7	
CS/HSS/100/04		4/4/2025		5771.0	1710	1641	28	107.4	4.8	4.1
CS/HSS/100/05				5305.7	1572			76.0	3.4	
CS/HSS/100/06				5539.8	1641			92.4	4.1	

Tested By : Ancel	Checked By : Caleb
Date :	Date :

KYAMBOGO									
CONCRETE LABOR				l S g h BS 1881 P					
								C m Typ & S 32 5N T M	
FLEXURAL STRENGTH OF CONC									
FLEXURAL STRENGTH OF CONCRETE 25% QUARTER SIZE SEED									

Table A.4.1: Modulus of Elasticity

	Specimen		deflection		deflection			Modulus of
				0 628				

CONCRETE LABORATORY

	Specimen		
		0 9846	
			1 8895
			0 87335

Table A.4.3: Water Absorption

	Specimen	Weight in air				Absorbed	Absorption
		Before oven					
				7808 15			
					6898 1		
				6954 8			
				6193 3			
		6550 9			5867 95		
						305 85	
		6823 9		6343 9			
		6878 8					
			5418 95			586 95	

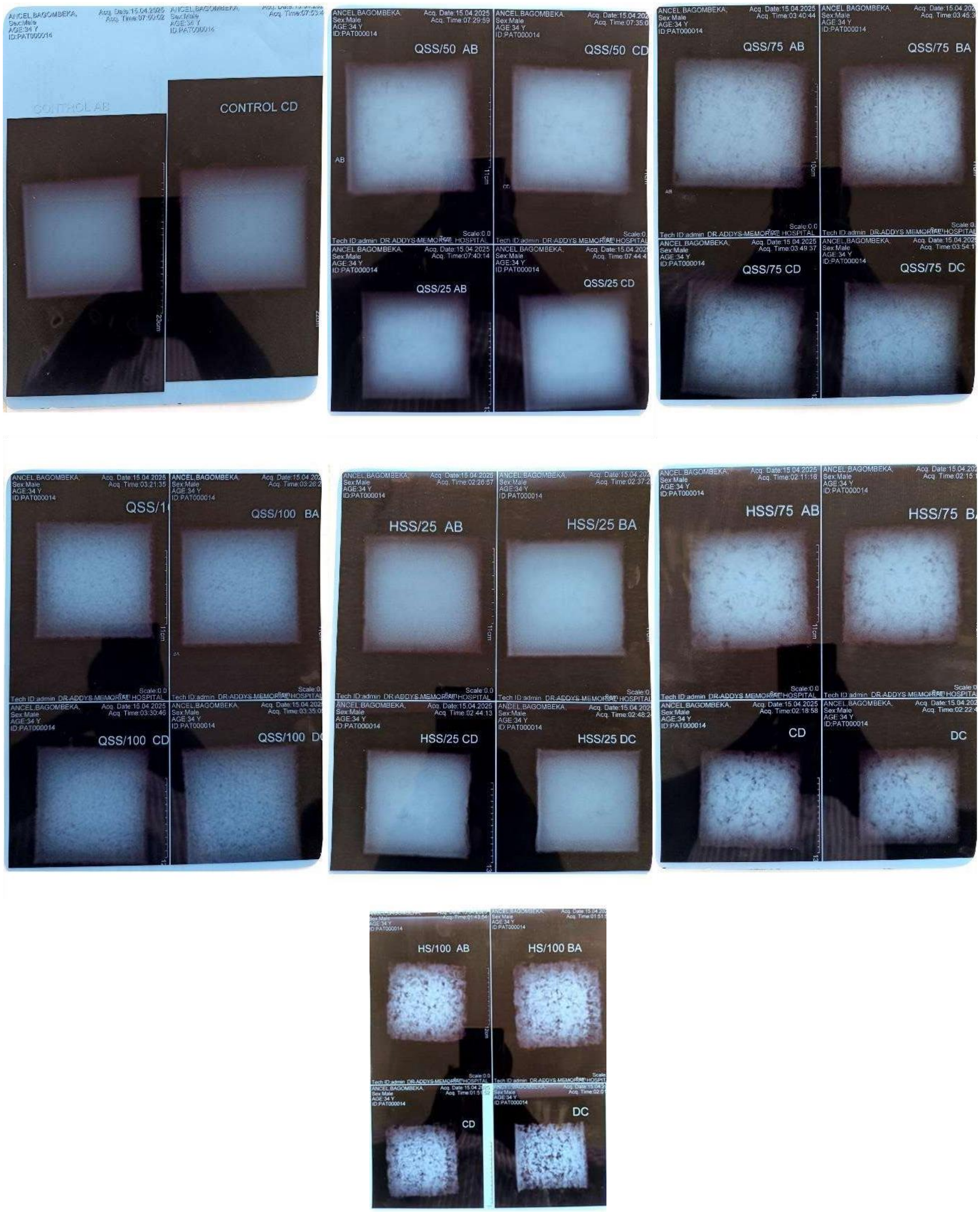

Fig. A.4.1: Digital X-ray Scan output

KYAMBOGO UNIVERSITY
FACULTY OF ENGINEERING
P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643
Department of Civil and Environmental Engineering

April 9, 2025

The Director,
ADDY Memorial Hospital

Dear Prof./Dr/Eng./Sir/Madam,

RE: LETTER OF INTRODUCTION FOR MR.BAGOMBEKA ANCEL

TO UNDERTAKE HIS FINAL YEAR RESEARCH IN MASTERS OF SCIENCE IN STRUCTURAL ENGINEERING

This is to introduce to you the above mentioned student Reg. Number 23/U/GMES/0528/PE pursuing Masters of Science in Structural Engineering. Mr. B intends to carry out his research on ***Evaluating the Mechanical Performance of Using KUKUI Seed Shells as Coarse Aggregates in Light Weight Aggregate Concrete*** in partial fulfillment of the requirements for the award of Master of Science in Structural Engineering.

This is therefore to request your Organization/Company/ Institution to grant him permission to carry-out his study.

Any assistance rendered to him will be highly appreciated.

Yours Sincerely,

KYAMBOGO UNIVERSITY
9 - APR 2025
DEPARTMENT OF CIVIL & ENVIRONMENTAL

Ssaalongo Luwalagga Munzi
Ag. Head, Civil and Environmental Engineering

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING
P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643
Department of Civil and Environmental Engineering

April 9, 2025

The Head,
College of Engineering Design,
Art & Technology,
Makerere University Material Lab,

Dear Prof./Dr/Eng./Sir/Madam,

RE: LETTER OF INTRODUCTION FOR MR.BAGOMBEKA ANCEL

TO UNDERTAKE HIS FINAL YEAR RESEARCH IN MASTERS OF SCIENCE IN STRUCTURAL ENGINEERING

This is to introduce to you the above mentioned student Reg. Number 23/U/GMES/0528/PE pursuing Masters of Science in Structural Engineering. Mr. Bagombeka Ancel intends to carry out his research on ***Evaluating the Mechanical Performance of using KUKUI seed Shells as Coarse Aggregates in Light Weight Aggregate Concrete*** in partial fulfillment of the requirements for the award of Master of Science in Structural Engineering.

This is therefore to request your Organization/Company/ Institution to grant him permission to carry-out his study.

Any assistance rendered to him will be highly appreciated.

Yours Sincerely,

KYAMBOGO UNIVERSITY
9 - APR 2025
DEPARTMENT OF CIVIL & ENVIRONMENTAL

Ssalongo Luwalagga Muzzi
Ag. Head Civil and Environmental Engineering

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA

Website: www.kyu.ac.ug Email: civil@kyu.ac.ug Tel: +256-41-4287340, FAX: +256-41-4289056/4222643

Department of Civil and Environmental Engineering

April 9, 2025

The Head Physics Department
Makerere University

Dear Prof./Dr/Eng./Sir/Madam,

RE: LETTER OF INTRODUCTION FOR MR.BAGOMBEKA ANCEL

TO UNDERTAKE HIS FINAL YEAR RESEARCH IN MASTERS OF SCIENCE IN STRUCTURAL ENGINEERING

This is to introduce to you the above mentioned student Reg. Number 23/U/GMES/0528/PE pursuing Masters of Science in Structural Engineering. Mr. Bagombeka Ancel intends to carry out his research on ***Evaluating the Mechanical Performance of using KUKUI seed Shells as Coarse Aggregates in Light Weight Aggregate Concrete*** in partial fulfillment of the requirements for the award of Master of Science in Structural Engineering.

This is therefore to request your Organization/Company/ Institution to grant him permission to carry-out his study.

Any assistance rendered to him will be highly appreciated.

Yours Sincerely,

KYAMBOGO UNIVERSITY
9 APR 2025
DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

Ssaalongo Luwalagga Munzi
Ag. Head Civil and Environmental Engineering

KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONCRETE AND HIGHWAYS LABORATORY

17th July 2025

TO WHOM IT MAY CONCERN

RE: <u>CONFIRMATION OF LABORATORY TESTS CONDUCTED AT CONCRETE MATERIALS LABORATORY</u>

This is to certify that Bagombeka Ancel is a Master of Science student in Structural Engineering at Kyambogo University and he carried out part of his research work at our laboratory.

The student conducted a series of laboratory tests related to his thesis titled: **"Evaluating the Performance of Kukui Seed Shells as Coarse Aggregates in Lightweight Aggregate Concrete."**

All relevant tests including but not limited to material characterization, concrete mix preparation and mechanical strength evaluations were conducted at our Laboratory under the supervision and guidance of our technical staff.

We confirm that the laboratory facilities were made available to support the student's academic research, and the tests were successfully completed in accordance with standard laboratory procedures and safety guidelines.

Page 1 of 2

Please do not hesitate to contact us should you require any further information.

Sincerely,

MULIGI MUNIRU
LABORATORY TECHNICIAN
CONCRETE LABORATORY
mmuligi@kyu.ac.ug

LOKOI RWOTH KOMOL
LABORATORY ATTENDANT
CONCRETE LABORATORY
rlokoi@kyu.ac.ug

ADDY MEMORIAL HOSPITAL

Healthcare with Dignity

15th July 2025

The Head,

Civil and Environmental Engineering,

Kyambogo University

Dear Prof. Dr./ Eng./ Sir/ Madam

RE: CONFIRMATION OF XRAY TESTS CONDUCTED

This is to confirm that BAGOMBEKA ANCEL, a student of Kyambogo University, conducted X-ray tests using our Digital X-ray machine on his concrete cubes at ADDY MEMORIAL HOSPITAL between 13th April 2025 and 15th April 2025. The test was conducted as part of an academic requirement for his thesis titled "Evaluating the mechanical performance of kukui seed shells as coarse aggregates in light weight aggregate concrete"

Please do not hesitate to contact us for any further information.

Sincerely,

ADDY MEMORIAL HOSPITAL LTD. 15 JUL 2025 Healthcare With Dignity

Dr. Colin Karaiga

Plot 15/16 Bahai Rd, P.o ebox 141994 Kampala. Tel;+256 775 067056 / 256 755 738145 emailaddyhospital84@gmail.com

MAKERERE UNIVERSITY

P. O. Box 7062, Kampala–Uganda
Cables: 'MAKUNIKA'
Website: www.mak.ac.ug

Tel: +256 412 531498
Fax: +256 412 531061
E-mail: physics@physics.mak.ac.ug
Website: www.physics.mak.ac.ug

DEPARTMENT OF PHYSICS

17th July, 2025

TO,
THE HEAD OF DEPARTMENT,
CIVIL AND ENVIRONMENT ENGINEERING,
KYAMBOGO UNIVERSITY,
P. O. BOX 1,
KYAMBOGO.

Re: **BAGOMBEKA ANCEL**

This is to confirm that Mr. Bagombeka Ancel carried out measurements of Thermal conductivity in one of our laboratories at the department of Physics, Makerere University. The measurements were carried out under the guidance of Mr. Bwambale Ronald – a *staff member* at the department of physics.

Yours sincerely,

MAKERERE UNIVERSITY
HEAD
17 JUL 2025
DEPARTMENT OF PHYSICS
P.O.BOX 7062, KAMPALA (U)

....

Dr. Daniel Muklibi
Senior Lecturer
Ag. Head, Department of Physics

BUSITEMA UNIVERSITY
Pursuing Excellence

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Fax: +256-45436517
Email:adm@proc.busitema.ac.ug
Website: www.busitema.ac.ug

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF POLYMER, TEXTILE & INDUSTRIAL ENGINEERING

22nd April 2025

The Head,

Civil and Environmental Engineering,

Kyambogo University

Dear Prof. Dr./ Eng./ Sir/ Madam

RE: <u>ANALYSIS OF KUKUI SEED SHELLS ON SEM</u>

Two samples of kukui seed shells were received in the metallurgy laboratory to be analyzed on the Scanning Electron Microscope (SEM). During the analysis, the presented samples were prepared and analyzed using the TESCAN VEGA 3 SEM equipment with serial number SBU. 118-0015, BERNIE, Czech Republic.

The results were sent to the student's email (Bagombeke Ancel) for further processing and analysis.

For more information on this contact;

....

Tumusiime Godias

Senior Technician

0701240292

BUSITEMA UNIVERSITY
FACULTY OF ENGINEERING AND TECHNOLOGY
22 APR 2025
DEPARTMENT OF POLYMER, TEXTILE & INDUSTRIAL TRAINING

Appendix A.6 :Pictures

f. Samples

g. Riffling of sample

h. Shaking sample using stack of sieves

i. Weighing sample retained on sieve

Figure A.6.1: Pictures showing sieve analysis of some samples

a. Samples being saturated in glass jars

b. Some samples taken to the oven for drying

Figure A.6.2: Pictures showing pycnometer test of some samples

a. Stack of flakiness sieves

b. Weighing sample retained on flakiness sieve after sieve analysis

Table A.6.3: Pictures showing Flakiness Index test of some samples

a. Sieving sample before AIV test

b. AIV test. Sieving is done after the test and the sample is weighed again

Figure A.6.4: Pictures showing Aggregate Impact Value test of some samples

a. Steel cylinder with sample undergoing crushing in the crushing machine

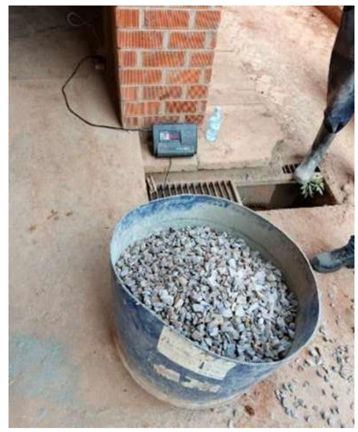
b. Sieving is done after the test and the sample is weighed again

Figure A.6.5: Pictures showing Aggregate Crushing Value test of some samples

a. CEM II, 32.5N (Tororo) Cement used

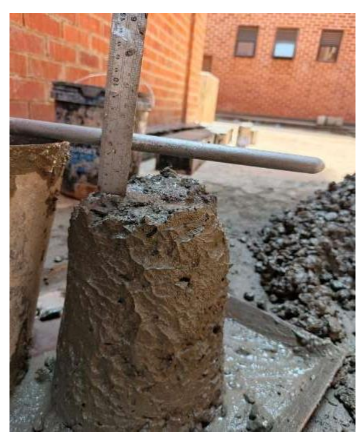
b. Weighing of Lake Sand before mixing

c. Weighing of seed shells before mixing



d.Weighing of coarse aggregates before mixing

Figure A.6.6: Pictures showing weighing of different materials during partial replacement and mixing



a. 100% Coarse Aggregates (60mm)

b. 25% Quarter Size Shell (48mm)

c. 50% Quarter Size Shell (10mm)

d. 75% Quarter Size Shell (0mm)

e. 100% Quarter Size Shell (0mm)

f. 25% Half Size Shell (25mm)

g. 50% Half Size Shell (5mm)

h. 75% Half Size Shell (0mm)

i. 100% Half Size Shell (0mm)

Figure A.6.7: Slumps for different partial replacement percentages

a. Some of the samples before being removed from the moulds

b. Some of the samples after being removed from the moulds

c. Concrete samples being labelled before soaking

Figure A.6.8: Pictures of concrete samples before testing

Concrete cubes being dried before testing

Figure A.6.9 : Concrete cubes being weighed

Concrete cubes being placed in the compression machine

a. CS/QSS/100/01 readings

b. CS/QSS/75/02 readings

Figure A.6.10 : Compressive test being carried out

Figure A.6.11 : Concrete beams being weighed

Figure A.6.12 : Flexural Strength Test being carried out

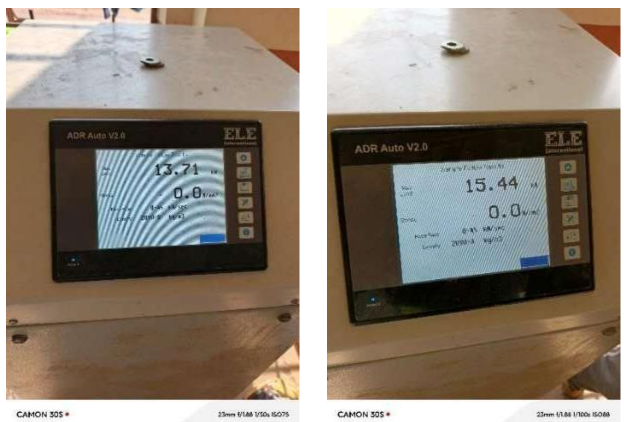


Figure A.6.13 : Flexural Strength Test results

Figure A.4.14 : Concrete cylinders being weighed

Figure A.6.15 : Splitting Tensile Strength Test being carried out

Figure A.6.16 : Splitting Tensile Strength Test results

Figure A.6.17 : Modulus of Elasticity Test being carried out

Figure A.6.17 : Thermal Conductivity Test

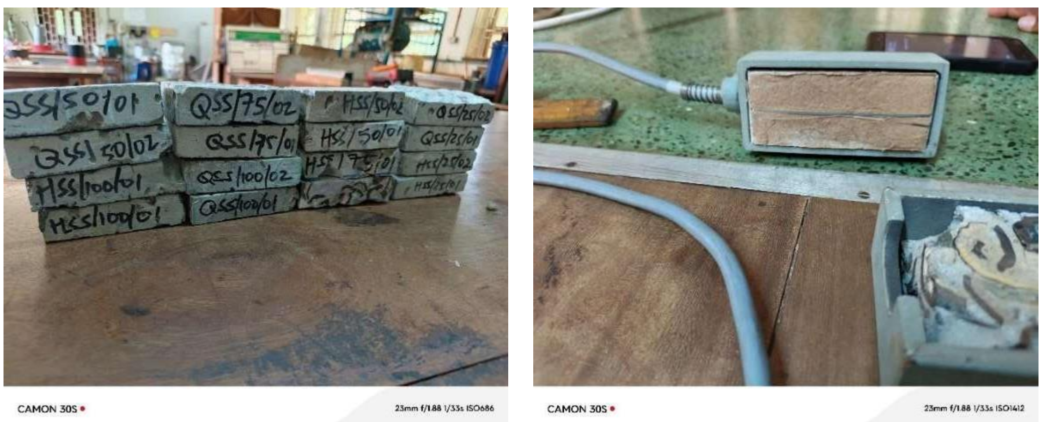


Figure A.6.19 : Thermal Conductivity Test Samples

Figure A.6.20 : Thermal Conductivity Test results

Figure A.6.21 : X-ray Test

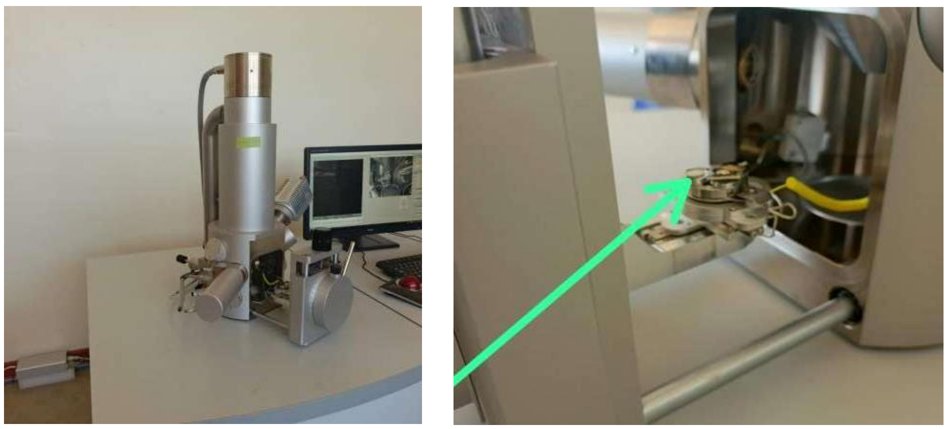


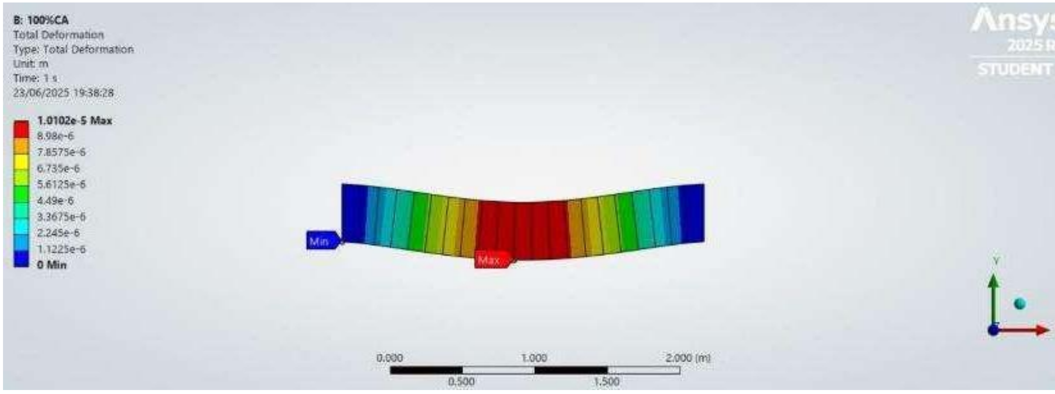
Figure A.6.22: SEM test

Figure A.6.23: Water Absorption cubes being weighed after being soaked

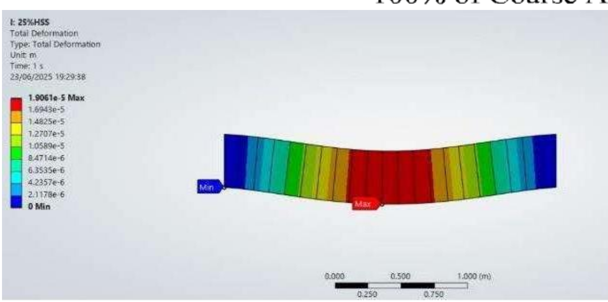
Figure A.6.24: Water Absorption cubes being placed in oven

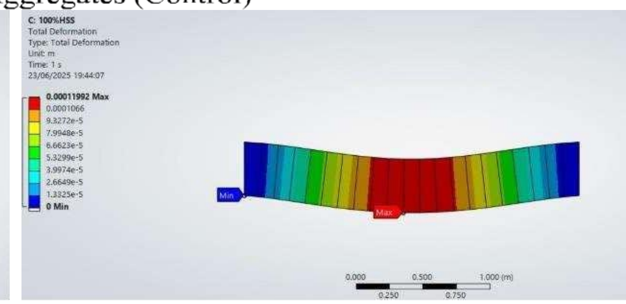
Figure A.6.25: Water Absorption cubes after oven drying

Figure A.6.26: Fire resistance



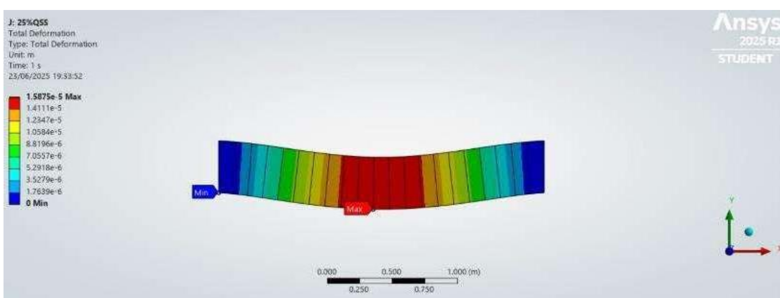
100% of Coarse Aggregates (Control)

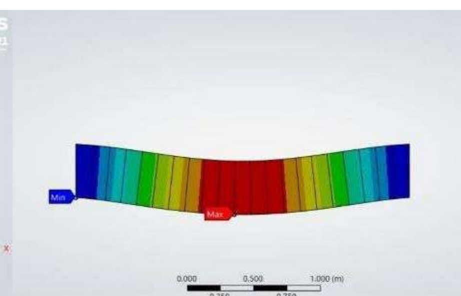




25% of Half Seed Shells

100% of Half Seed Shells

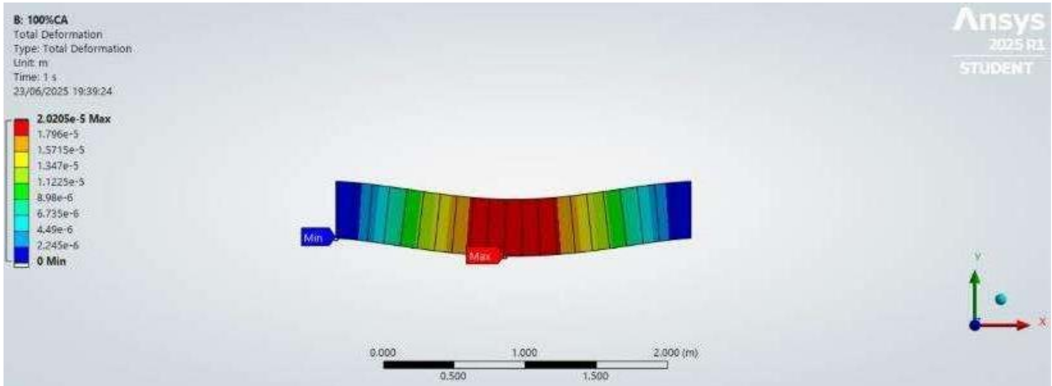




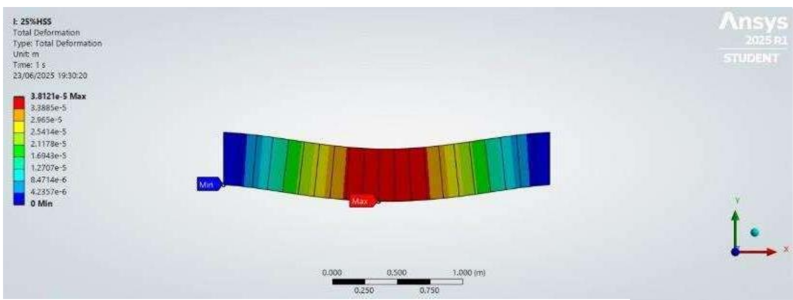
25% of Quarter Seed Shells

100% of Quarter Seed Shells

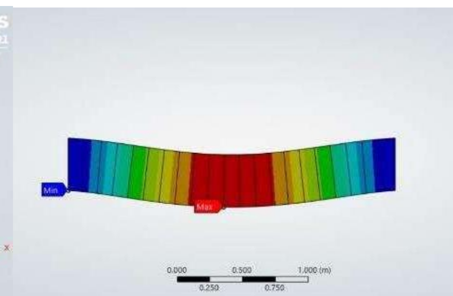
Figure A.6.27: Finite Element Analysis output for point load of 5000N



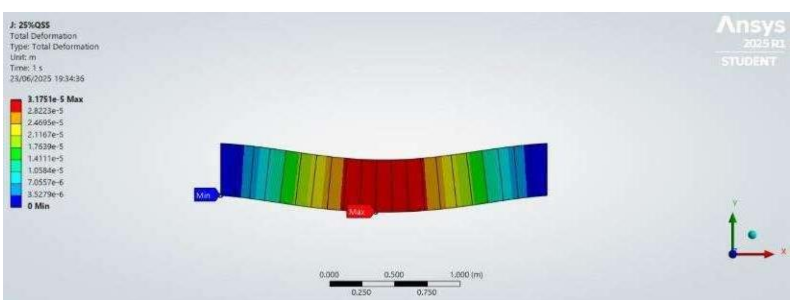
100% of Coarse Aggregates (Control)



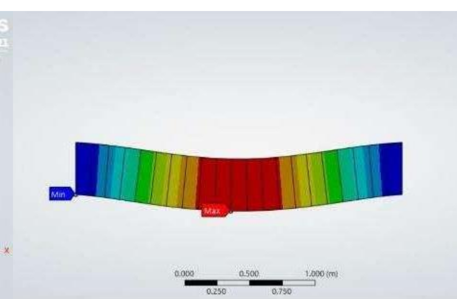
25% of Half Seed Shells



100% of Half Seed Shells

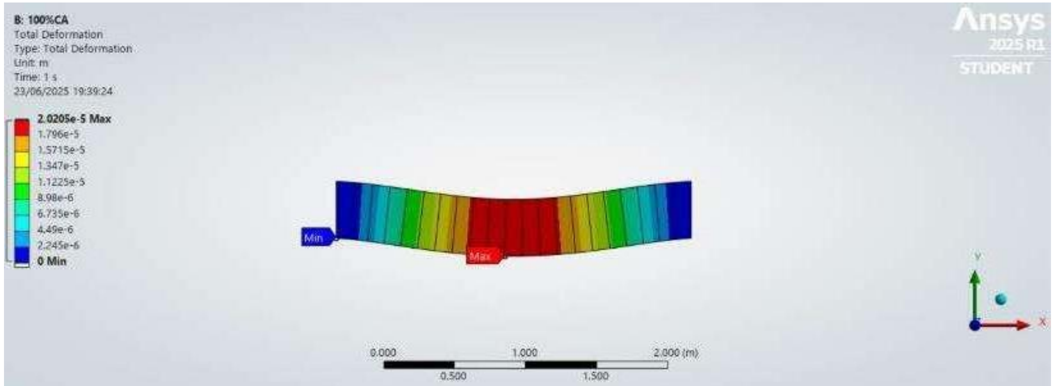


25% of Quarter Seed Shells

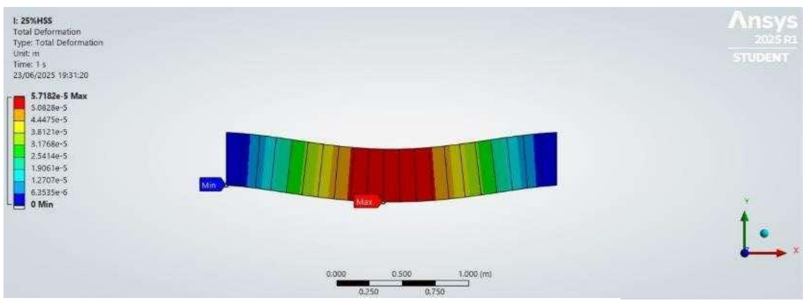


100% of Quarter Seed Shells

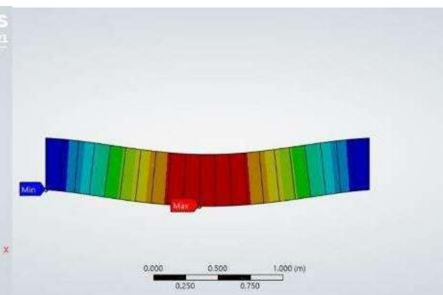
Figure A.6.28: Finite Element Analysis output for point load of 10000N



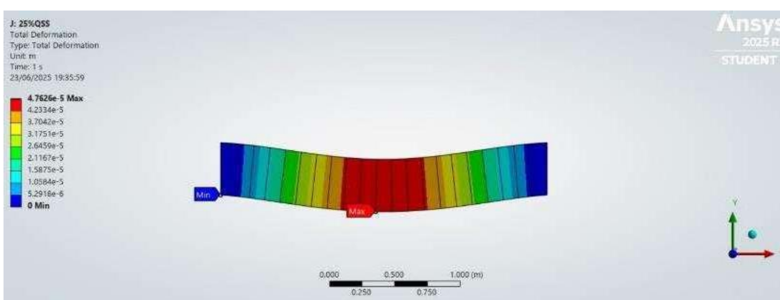
100% of Coarse Aggregates (Control)



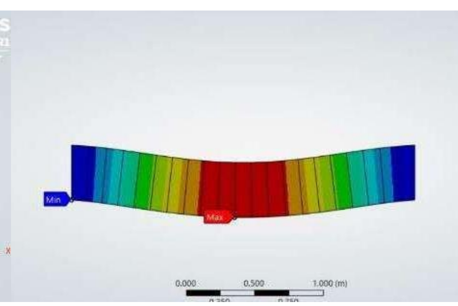
25% of Half Seed Shells



100% of Half Seed Shells

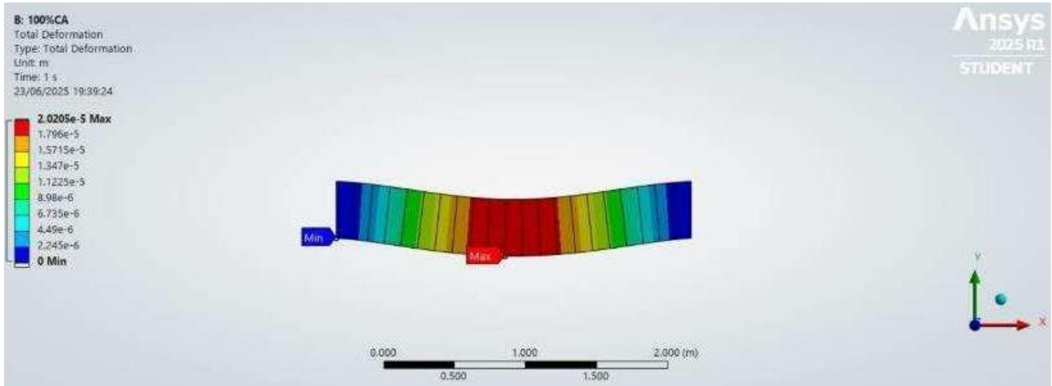


25% of Quarter Seed Shells

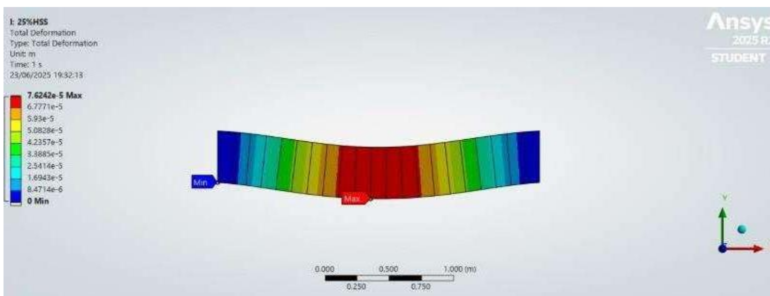


100% of Quarter Seed Shells

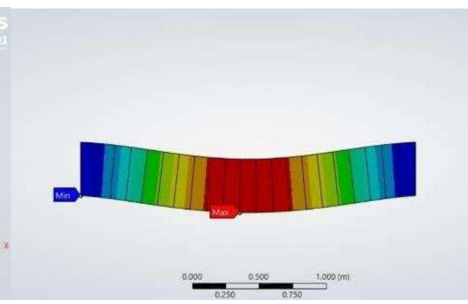
Figure A.6.29: Finite Element Analysis output for point load of 15000N



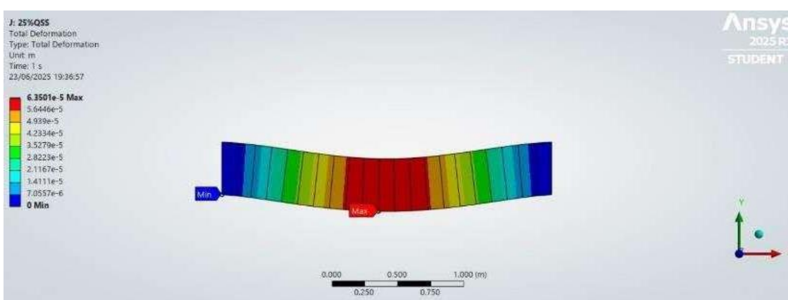
100% of Coarse Aggregates (Control)



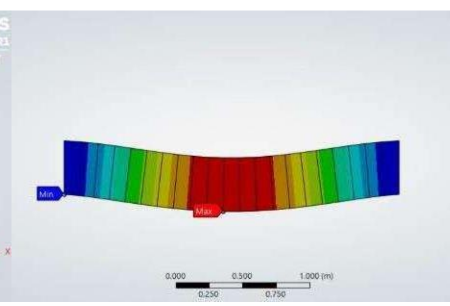
25% of Half Seed Shells



100% of Half Seed Shells



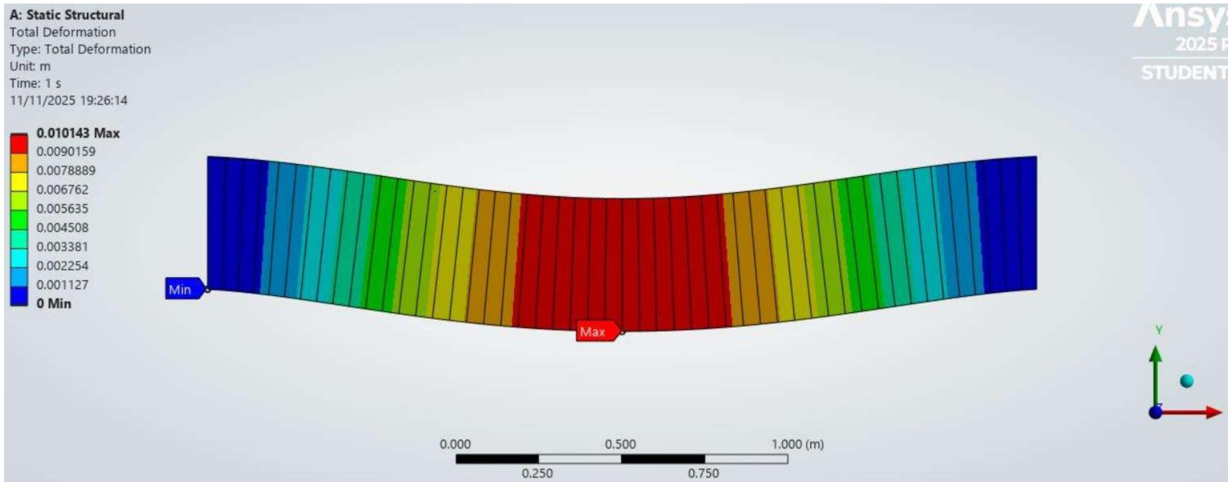
25% of Quarter Seed Shells



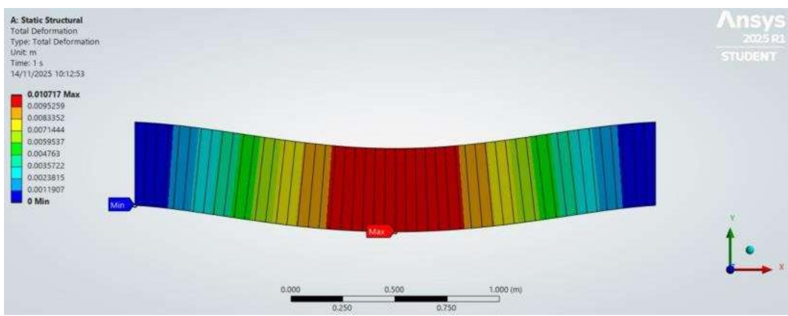
100% of Quarter Seed Shells

Figure A.6.30: Finite Element Analysis output for point load of 20000N

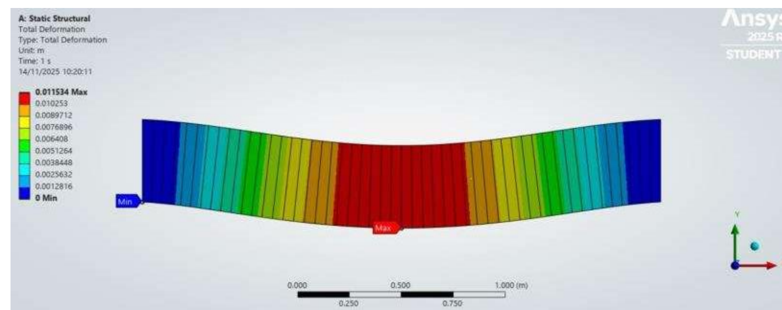
MAXIMUM POINT LOAD AT MAXIMUM DEFLECTION



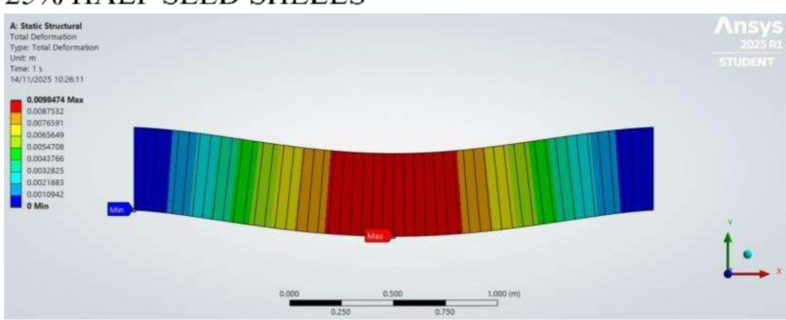
100% COARSE AGGREGATES



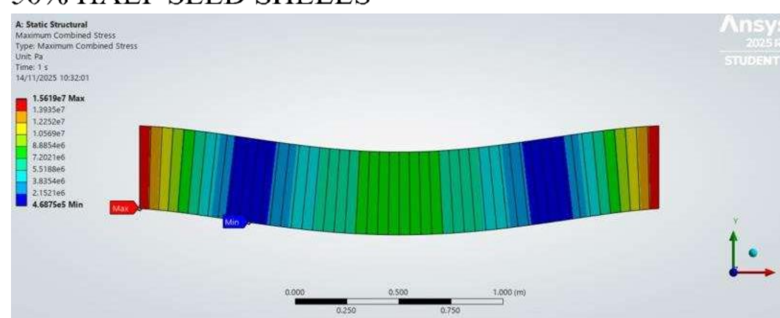
25% HALF SEED SHELLS



50% HALF SEED SHELLS

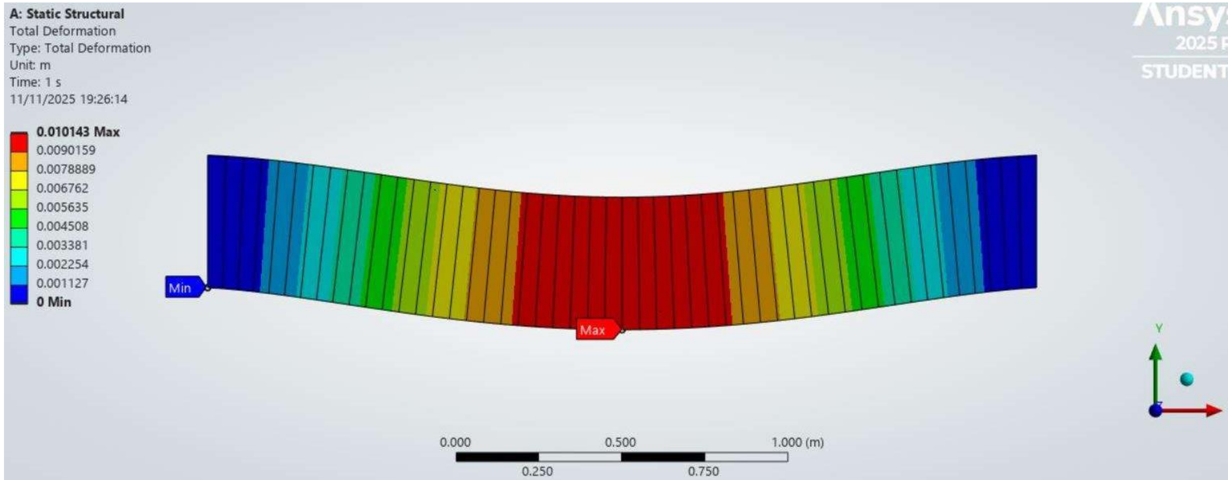


75% HALF SEED SHELLS

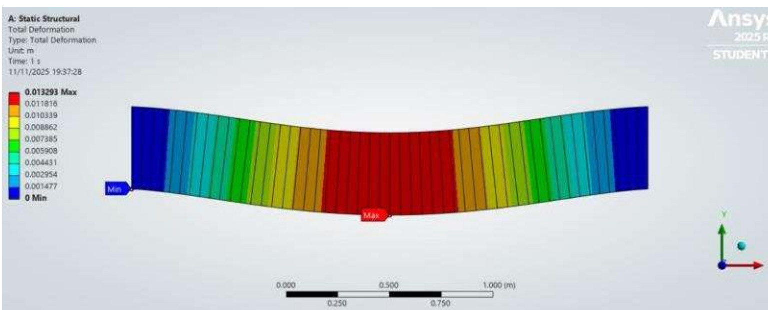


100% HALF SEED SHELLS

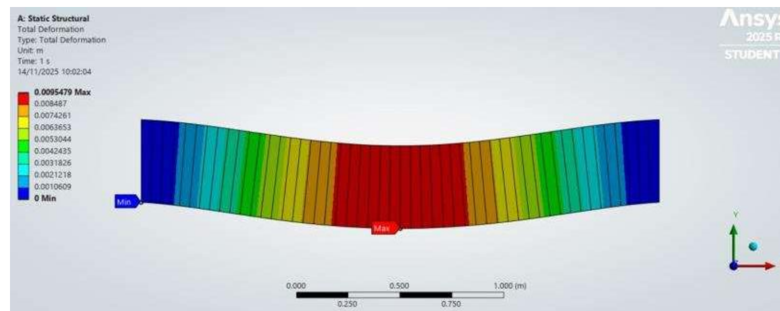
MAXIMUM POINT LOAD AT MAXIMUM DEFLECTION



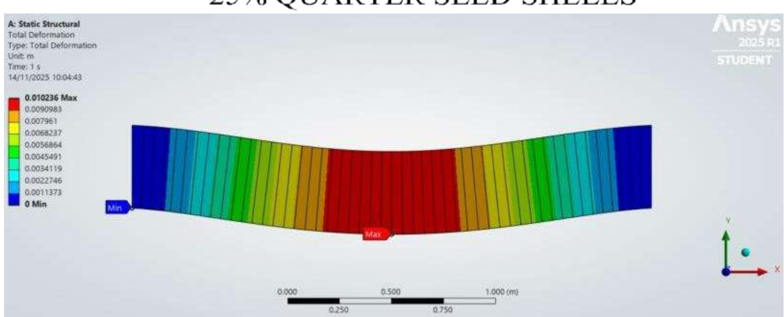
100% COARSE AGGREGATES



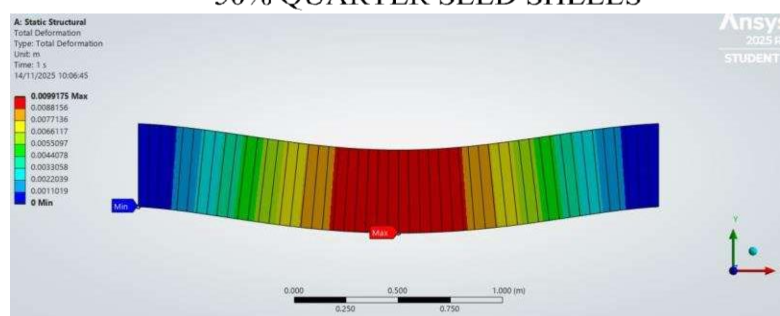
25% QUARTER SEED SHELLS



50% QUARTER SEED SHELLS

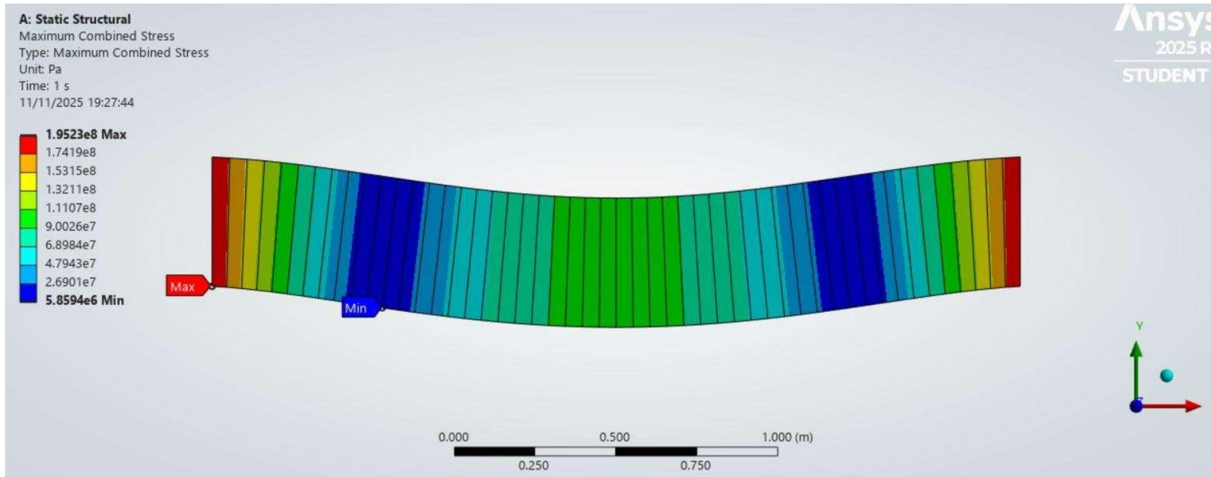


75% QUARTER SEED SHELLS

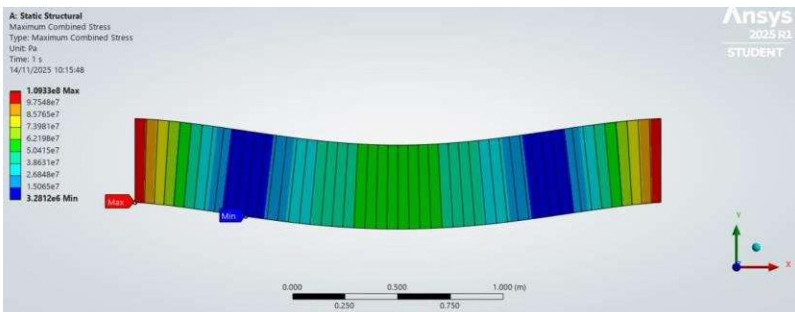


100% QUARTER SEED SHELLS

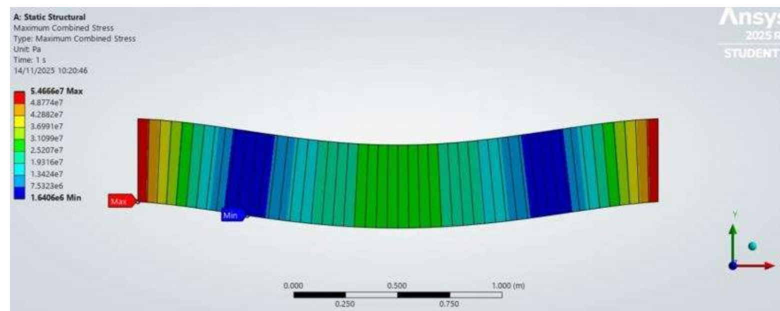
MAXIMUM COMBINED STRESS AT MAXIMUM DEFLECTION



100% COARSE AGGREGATES



25% HALF SEED SHELLS



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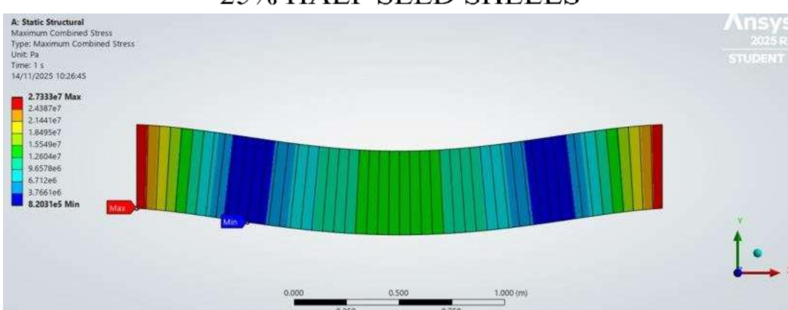

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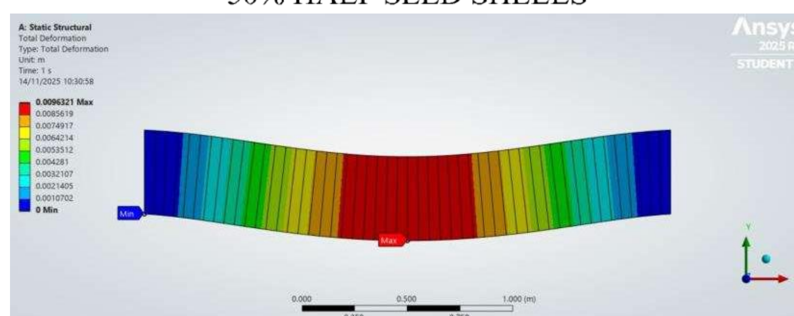
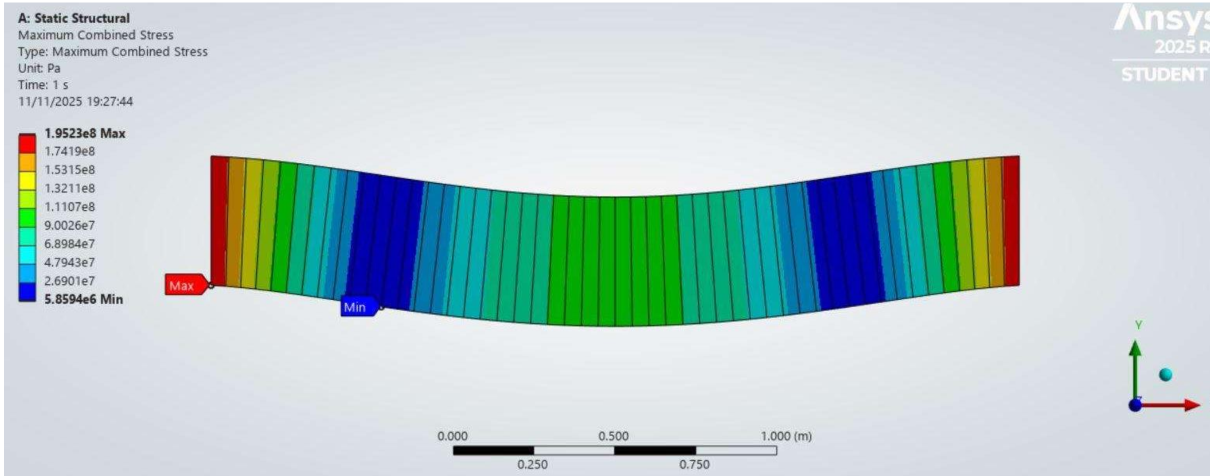


100% HALF SEED SHELLS

MAXIMUM COMBINED STRESS AT MAXIMUM DEFLECTION



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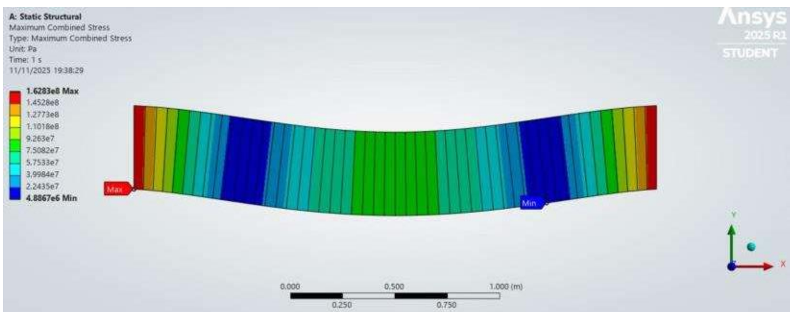

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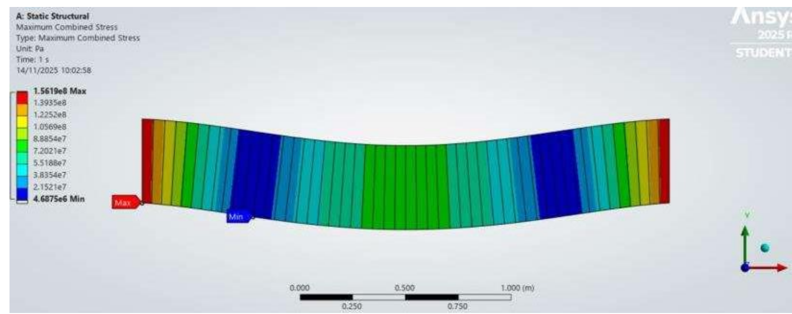

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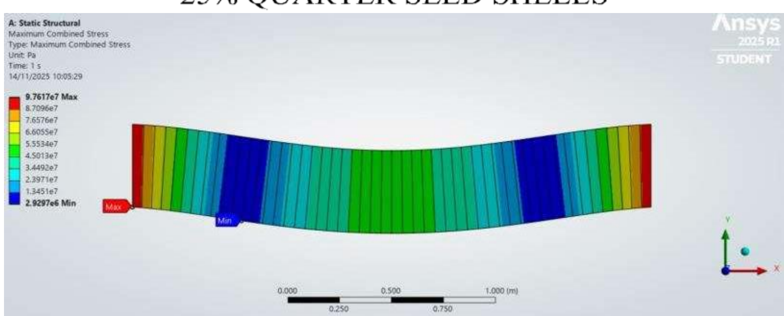

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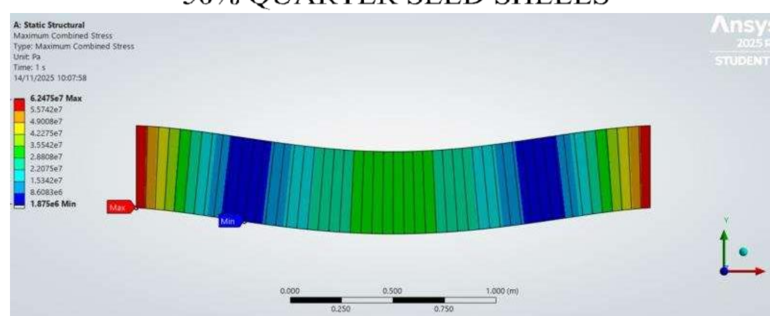

100% QUARTER SEED SHELLS