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Evaluating the mechanical performance of Kukui seed shells as coarse aggregates in light weight aggregate concrete

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Abstract
Uganda's population growth, currently at 3.2%, has increased the demand for residential, commercial, and industrial buildings. Concrete constitutes nearly 60% of construction materials on building sites, and aggregates contribute 70–85% of its total weight. 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 possible 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 characterisation 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/m^3, 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

1 Introduction

The construction industry plays a great role in meeting society's needs by improving the quality of life [4]. There is an argument that the international construction market is forecasted to grow by 85% to USD 15.5 trillion by 2030 [5]. The construction industry further contributes to the development of both developing and developed countries and economies by supplying shelter and infrastructure [6]. Uganda has a population base of 45 million and a high population growth rate of 3.2%, making it one of the fastest-growing populations in Africa [1]. 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 [2]. 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.

With a high demand for building construction, the need for aggregates rises, resulting in a strain on existing normal aggregate sources, and this therefore necessitates alternative sources of coarse aggregates [7]. Most of the infrastructure in the world are built with concrete [8]. Coarse aggregates typically accounts for about 75% of the concrete volume [9]. The different qualities and kind of aggregates determine different durability and workability that affect the concrete [10]. According to the Uganda Bureau of Statistics (UBOS) construction price index, the demand for aggregates increased by 4% between February 2023 and February 2024 [21]. 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.

One alternative coarse aggregate is Light Weight Aggregates. One of the advantages of Light Weight Aggregates Concrete is its ability to reduce the overall self-weight of structures [11] creating lighter high-rise structures when used as an alternative to normal coarse aggregates. Different types of light weight aggregates 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, (Canndle nut tree) is a flowering tree (normally it grows up to 20 m in height) belonging to the Euphorbiaceae family. Its species name is AleuritesMoluccanus. The tree is native to the Indo-Malaysia region and became one of the world's great domesticated multipurpose trees [12]. 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 [13] The tree takes four years to grow and start bearing significant fruit [14] It bears around 80 kg of seeds per tree [15]. This amounts to approximately 90 trees being planted in a hectare.

An average seed yields about 10–40% of oil [16]. 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 [15] or as feedstock for biomass. The kukui seed shells can also be an alternative renewable energy source [17]. 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 [18]. 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 since

2009. They deal in bio-diesels, briquettes, and many other products. Currently, they have a biodiesel production facility in Mukono district (Uganda) with a capacity to produce 60,000 L of biodiesel per day, which amounts to about 18 million 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 2000 kg/m3 [19]. The kukui seed shell density is 1140 kg/m3 [20]. This puts kukui shells under the category of light weight aggregates. Apart from reducing the self-weight of the structure, the concrete with these seed shells improves the thermal insulation properties of the concrete it is incorporated in. These are just a few examples of how the kukui seed shells will improve on the mechanical properties of concrete.

2 Methods

2.1 Research design

The maximum nominal size for aggregates to be used in reinforced concrete is 20 mm. In the study, it was discovered that Quarter Seed Shells have a maximum particle size of 14 mm while Half Seed Shells have a maximum particle size of 20 mm. 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 paper. 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 h, 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 attachments.

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 Materials Laboratory of Kyambogo University and the Physics Department of Makerere University.

Table 1 Material properties

No.	Material	Property
1	Kukui seed shells	*Treatment* properly cleaned to remove any signs of cake. The samples were sun-dried.
2	Cement	CEM II (42.5 N) Portland Pozzolana Cement (PPC)
3	Aggregates	*Coarse Aggregates* aggregate size of a maximum of 20 mm. Fine aggregates: 0–5 mm in size
4	Water	Ordinary portable water was used
5	Concrete	Partial replacement of coarse aggregate vs. kukui seed shells at percentages of 0%, 25%, 50%, 75%, 100% (kukui seed shells)

Table 2 Mix ratios used during partial replacement mixing

No.	Particulars	Mix ratio	Cement	Sand	Aggregates	QSS	HSS	Water
1	Quarter seed shells (QSS)	100% QSS	61.86	103.76	0	94.81		30.93
		75% QSS	61.86	103.76	44.85	71.1		30.93
		50% QSS	61.86	103.76	89.7	30.92		30.93
		25% QSS	61.86	103.76	134.51	23.7		30.93
2	Half seed shells (HSS)	100% HSS	61.86	103.76	0		96.68	30.93
		75% HSS	61.86	103.76	44.85		72.48	30.93
		50% HSS	61.86	103.76	89.7		48.31	30.93
		25% HSS	61.86	103.76	134.54		24.16	30.93
3	Coarse aggregates (100%)	100%CA	61.86	103.76	179.38			30.93

2.2 Research approach

2.2.1 Experimental analysis

2.2.1.1 Material properties Table 1 shows different materialproperties used during the experiment.

2.2.1.2 Mix ratios of concrete for optimal composition The mix design was developed with reference to the recommended design strength of 25 MPa (C25). For consistency, the water-cement ratio was kept constant throughout all the partial replacement mixes using the water-cement ratio for the Control mix (which had 100% normal aggregates).

A constant water-cement ratio of 0.50 was intentionally maintained across all mixes to ensure experimental consistency and to enable direct comparison between the control mix and the kukui seed shell modified mixes. The chosen value aligns with typical proportions required to achieve the target control strength of 25 MPa at 28 days when using normal weight aggregates shared in the mix design calculations.

Therefore, we intentionally did not modify the water: cement ratio for each level of aggregate replacement. Instead, the study was designed such that any reductions in workability, density, or compressive strength reflect the inherent characteristics of the kukui seed shells, specifically their absorption and organic composition, rather than differences in mix-design parameters.

The omission of moisture conditioning was deliberate, to allow the study to capture the true, unmodified behavior of kukui shells when introduced into concrete without pre-treatment. This provides a clearer baseline understanding of how the shells affect concrete performance, which is essential before optimized pre-treatment strategies can be proposed.

Table 2 shows the various mix ratios that were used during the experiment. The densities of the constituents were used to get the weights.

2.2.1.3 Material coding Table 3 shows an example of how the material was coded depending on the type of kukui seed shell and the test carried out.

2.2.1.4 Material test program To ensure statistical reliability and reduce experimental variability, as recommended in [22] a minimum of 3 samples were selected for each batch of concrete tests. The Table 4 Shows the tests that were carried out, the specifications followed when carrying out the tests and the number of samples.

2.2.2 Numerical analysis

The Fig. 1 shows the simulation process used when executing the serviceability performance of the concrete member.

2.2.2.1 Simulation software Beam modelling and structural analysis were 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 type, of analysis no dynamic or lateral loads were assumed.

2.2.2.2 Material properties Concrete was used as a material because 60%of sites use it as a building material [2]. 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.

2.2.2.3 Beam geometry The geometric specification of the beam was a 400 mm high, 200 mm wide, and 2500 mm long beam. The minimum span-to-depth ratio recommended in Eurocode 2 is 20. The beam used is 2500 mm in length, so the minimum depth of the beam for that span was 125 mm, the use of a beam with 400 mm depth. It was modelled under "Design Modular" Figure 2 below shows the details of the beam geometry used in the simulation software.

2.2.2.4 Mesh generation Meshing is the discretization of a structure into finite elements. The beam was meshed using quadratic structured mesh of 50 mm size. Figure 3 below shows the meshing pattern and its key particulars

2.2.2.5 Boundary and loading conditions Afixed-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. 4 . (At x = 0 and x = 2.5 m; UX = 0, UY = 0, UZ = 0, ROTX = 0, ROTY = 0, ROTZ = 0)

2.2.2.6 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.

Table 3 Material coding guide

No.	Material test	Code	Description
01	Compressive strength	CS/QSS/"% partial replacement"/"no."	QSS- Quarter Seed Shell CS- Compressive Strength % partial replacement e.g. 75%QSS no. – the concrete cube number

Table 4 Test program

No.	Specific objectives	Tests	Reference	No. of samples	Significance
1	To determine the mechanical properties, physical properties and sizes of kukui seed shells to be used in concrete	Aggregate Crushing Value	BS812:Part 110:1990	3 samples	This is a test to check a material's ability to resist crushing loads. The lower the ACV value, the more resistant the material.
		Water Absorption	BS812:Part 109:1990	3 samples	This test is used in calculations for the concrete mix designs to determine the water needed for the mix.
		Grading Tests	BS812: Part 2:1975	3 samples	This test is used to determine the particle size distribution of aggregates, which would affect the quality and performance of the concrete.
		Flakiness Test (FI)	EN1992	3 samples	This test is used to determine the percentage of flaky particles in the aggregates. Flaky particles usually lead to weaker concrete, which breaks easily on heavy impact.
		Aggregate Impact Value	BS812:Part 112:1990	3 samples	This is a test to check a material's ability to resist impact loads. The lower the AIV value, the more resistant the material.
		Los Angeles Abrasion Test (LAA)	ASTM C535-89	3 samples	This is a method used to measure the resistance of aggregates to abrasion. The lower the LAA value, the more resistant to abrasion the material is.
		Soundness	BS882	3 samples	The ability of an aggregate to resist deterioration from weathering processes, particularly freeze-thaw cycles and wet-dry cycles.
		Morphology, and element composition (SEM)	ASTM E986-04:2017	3 sample	This test sheds more light on the chemical composition and arrangement of the grains in the seed shell.
2	To determine the mechanical properties of concrete that constitutes kukui seed shells	Compressive Strength	Mix design	54 cubes	The ability of the concrete to resist crushing. The higher the resistance, the better the concrete. A Universal Testing Machine was used to determine compressive strength due to variability in the accuracy of non-destructive testing methods across different material types [36].
		Flexural Strength	EN1992	27 beams	The ability of the beam to resist bending. The more resistant it is, the better the concrete.
		Modulus of Elasticity	EN1992	27cubes	The stress-strain relationship of the concrete. This will enable engineers to understand what happens under loading.
		Splitting Tensile Strength	EN1994	27 cylinders	The ability of the concrete to resist splitting. The higher the resistance, the better the concrete.
3	To determine the durability performance of concrete that constitutes kukui seed shells	Thermal conductivity	BS EN 1745	27 samples	The ability of a material to resist or allow transfer of heat through the material. The lower the value, the better it performs as an insulator.
		Fire resistance	BS8110-2:1985	27 cubes	Ability of a material to resist fire and its heat and remain within the parameters of specifications.
		Water Absorption	BS 6349	27cubes	The percentage of water that the concrete absorbs.
		Internal topography of the concrete cube (Digital X-ray machine)	ASTM F792	27 samples	This test draws more light on the internal structure of the hardened concrete

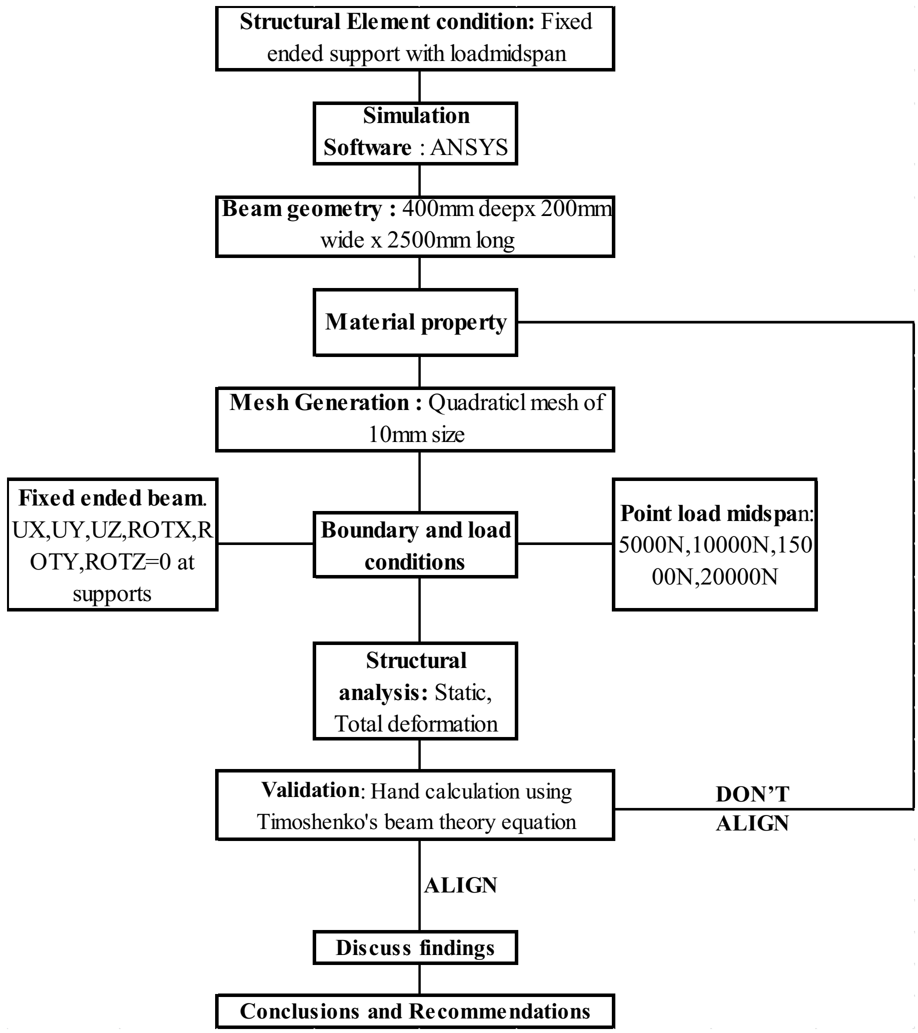


Fig. 1 Simulation process undertaken when carrying out the serviceability check

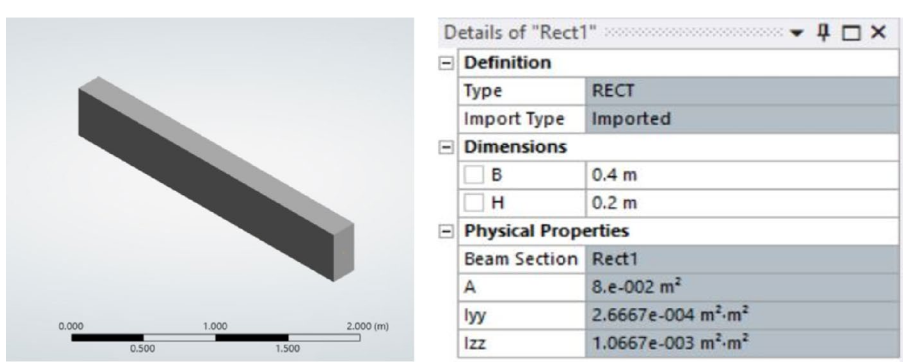


Fig. 2 Illustration of beam geometry

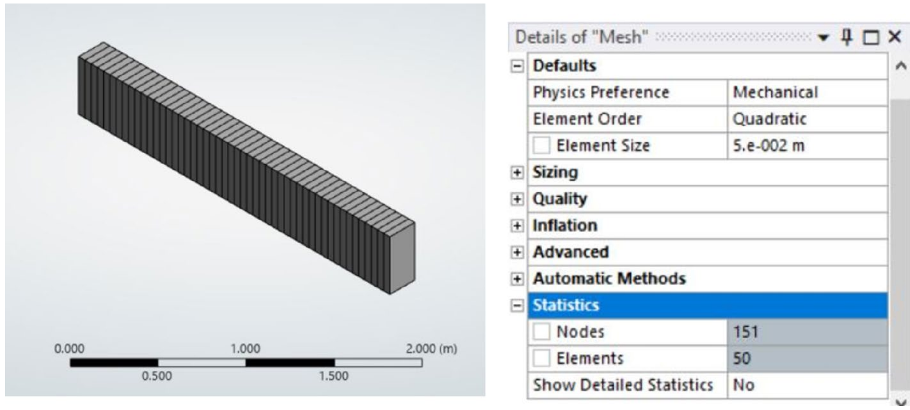


Fig. 3 Illustration of meshing pattern

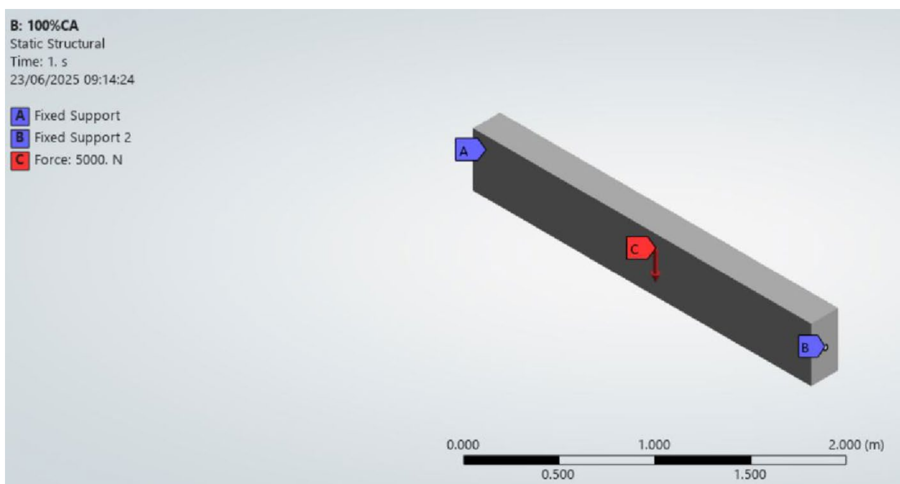


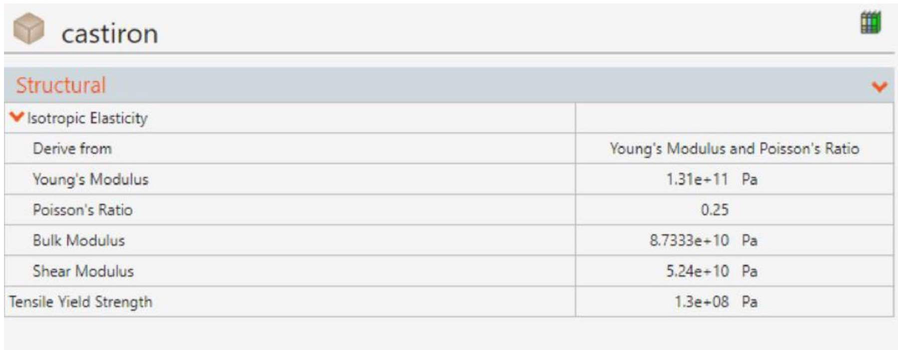
Fig. 4 Illustration of boundary and loading conditions

2.2.3 Validation

Under "Analysis of different Beams" [23], 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.

2.2.3.1 Material properties The properties of the beam used during validation are shown in Fig. 5:

2.2.3.2 Beam geometry In their study, they used a beam with the parameters shown in Fig. 6 :



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

Fig. 5 Material properties used in the ANSYS software [23]

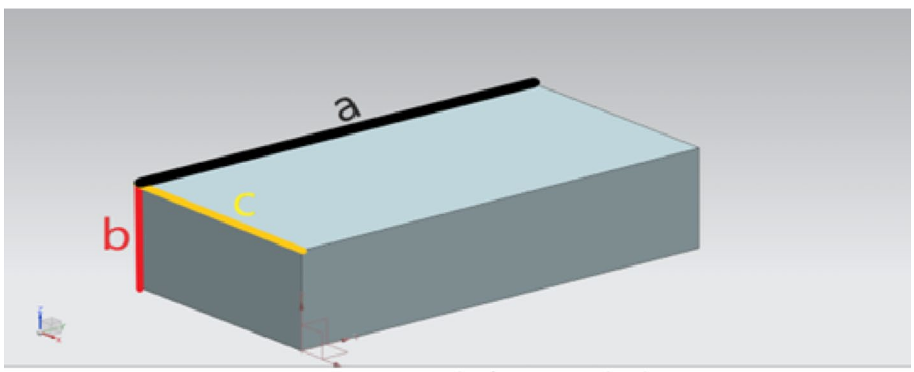
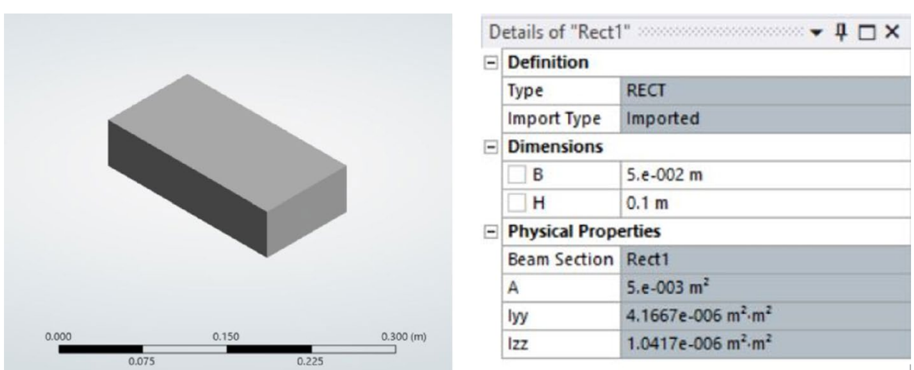


Fig. 6 Beam dimensions used in the research [23]



Details of "Rect1"

Definition	
Type	RECT
Import Type	Imported
Dimensions	
B	5.e-002 m
H	0.1 m
Physical Properties	
Beam Section	Rect1
A	5.e-003 m^2
Iyy	4.1667e-006 $m^2 \cdot m^2$
Izz	1.0417e-006 $m^2 \cdot m^2$

Fig. 7 Illustration of beam geometry in program

From Fig. 7, the height of the beam (b) was 50 mm, the width of the beam (c) was 100 mm, and the length of the beam (a) was 200 mm.

2.2.3.3 Mesh generation The beam was meshed using quadratic structured mesh of 10 mm size Fig. 8. shows the meshing pattern and key parameters of the beam.

2.2.3.4 Boundary and loading conditions A fixed-ended beam was envisioned (Fixed at A and B). Point loads (W) of 5000KN were applied midspan in the negative y direction

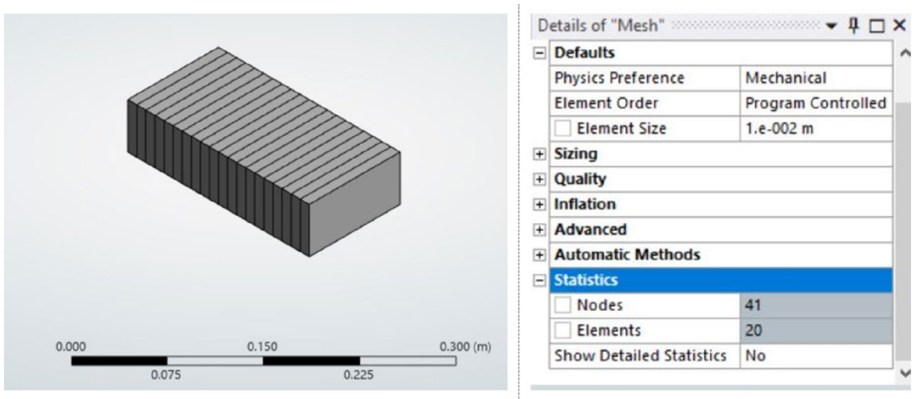


Fig. 8 Illustration of meshing pattern

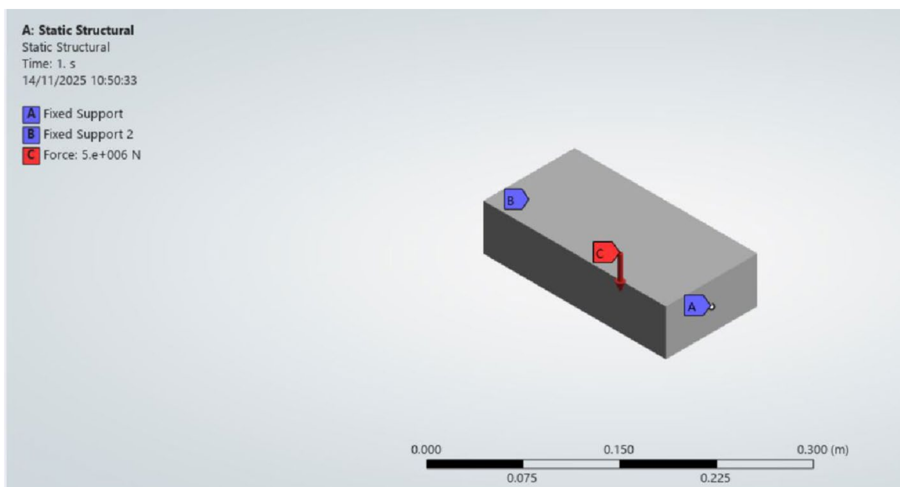


Fig. 9 Illustration of boundary and loading conditions

(gravity load) as shown in Fig. 9. (At x = 0 and x = 0.2 m; UX = 0, UY = 0, UZ = 0, ROTX = 0, ROTY = 0, ROTZ = 0)

2.2.3.5 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. Fig. 10 shows the output from the ANSYS analysis.

Furthermore, Table 5 shows the deflections derived from the analysis.

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 the analysis of deflection. Figure 11 shows the output for total deformation of a 100% coarse aggregate beam simulation under mid-span loading.

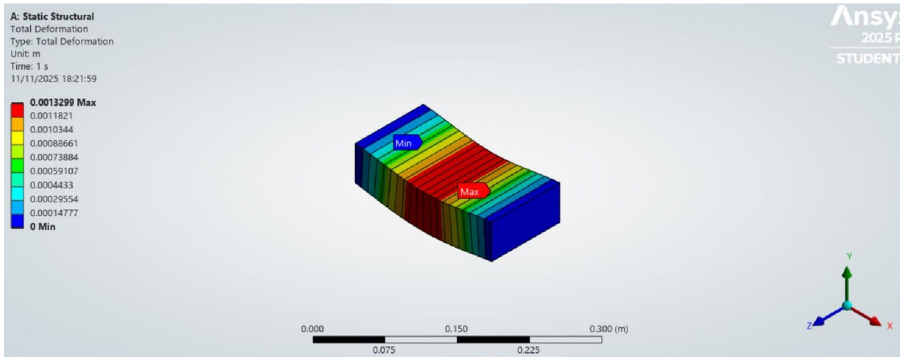


Fig. 10 Deflection output from ANSYS

Table 5 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						

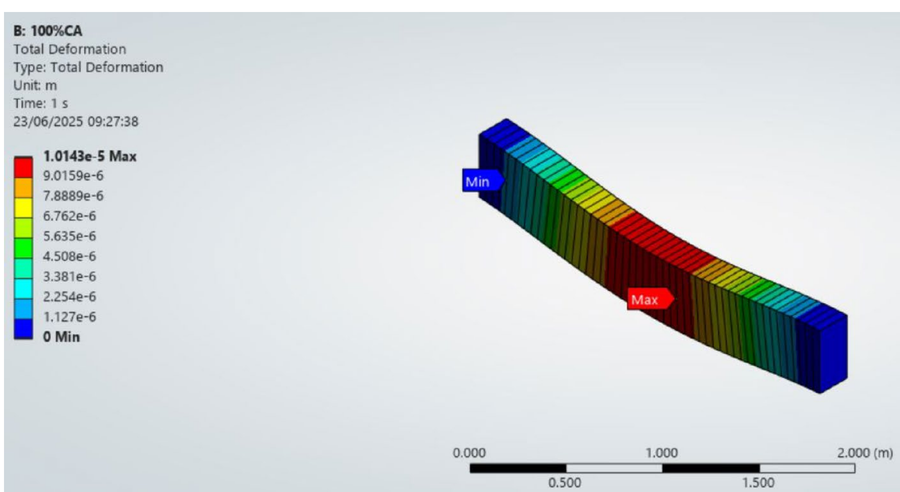


Fig. 11 Illustration of one of the outputs from the analysis

3 Results and discussions

3.1 Experimental analysis

3.1.1 Experimentation on the Kukui seed shells

3.1.1.1 Dimensions of the seeds Figures 12 and 13 show different dimensions and elevations of the seed shells that were used in the different tests that were carried out.

3.1.1.2 Morphology, internal topography, and element composition The Scanning Electron Microscope (SEM), which scanned the specimen and formed an ultra-high resolution image, was used to magnify the kukui seed shells and determine their chemical

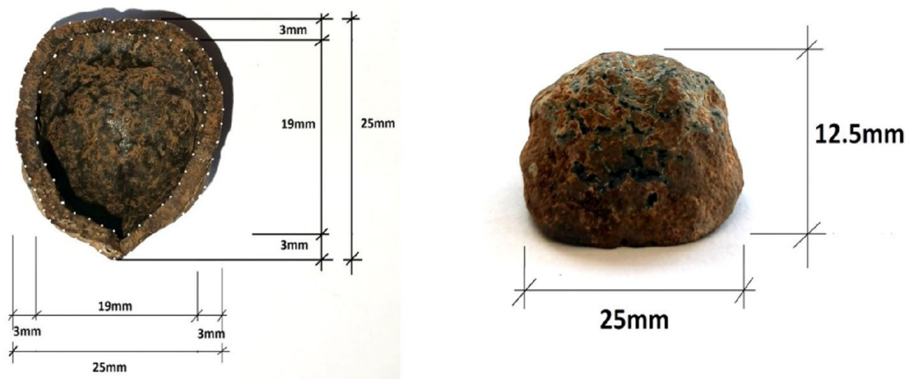


Fig. 12 Dimensions of half seed shell

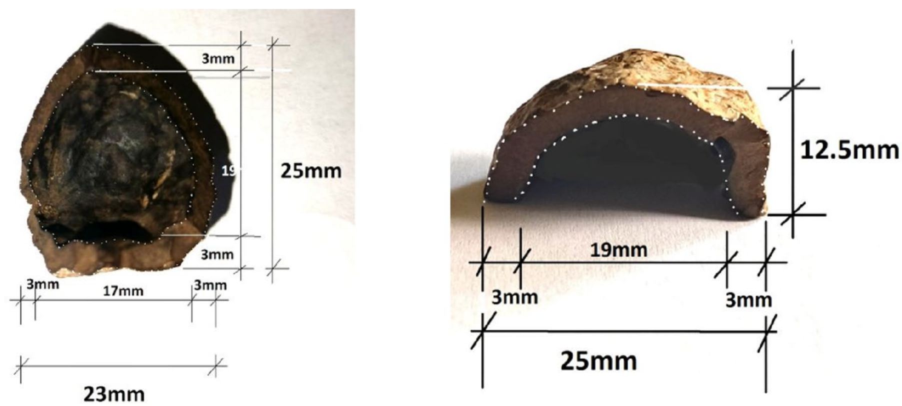
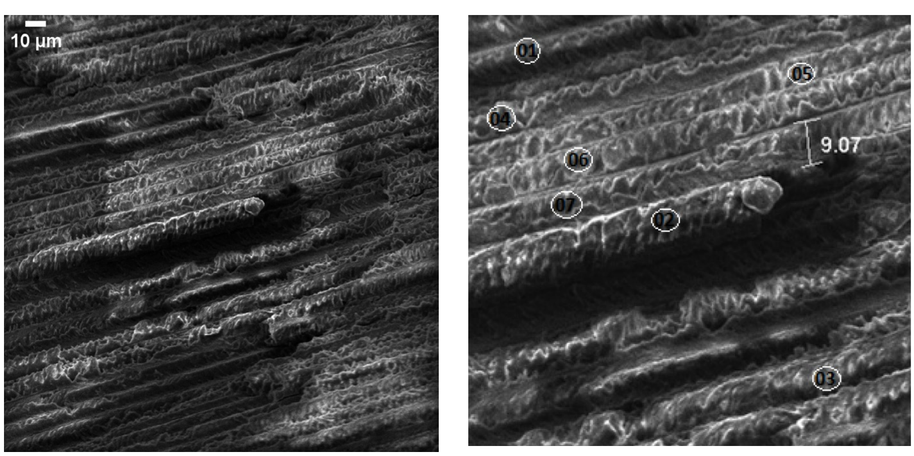


Fig. 13 Dimensions of quarter seed shell



Arrangement of layers

Thickness of layers

Fig. 14 Kukui seed shell microstructure

composition. The output of this magnification was shared, and it was determined that the longitudinal grains are arranged in thin layers connected in parallel to one another. Due to this, the mechanical properties of the seed shell parallel to the grains and those perpendicular to the grains are different. Figure 14 shows the different outputs from the SEM.

Table 6 Kukui seed shell layer thickness

Label	1	2	3	4	5	6	7	8	Mean	Min.	Max.
Thickness (micro meters)	10.73	9.49	8.94	6.07	8.52	9.95	9.07	9.92	**9.09**	**6.07**	**10.73**

Table 7 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

Table 8 Natural composition of the Kukui seed shell [22]

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

SEM observations were intended to provide qualitative insight into the internal structure of the kukui seed shells rather than to assert confirmed mechanical anisotropy. Although the SEM images suggested a layered or fibrous arrangement typical of biomass, which can exhibit anisotropic stiffness and fracture behavior, the manuscript now explicitly states that no directional mechanical tests (e.g., tension or compression along and across the fibre orientation) were conducted to validate anisotropy experimentally. This limitation has been acknowledged clearly to avoid over-interpretation. Consistent with the reviewer's concern, we emphasize that such behavior in Kukui Seed Shells should be confirmed through dedicated mechanical testing rather than inferred solely from SEM morphology. This clarification ensures that the conclusions remain scientifically grounded and within the limits of the conducted analyses.

Table 6 shows the different thicknesses of the layers of the Kukui Seed Shells:

Table 7 shows the different chemical compositions of the tested kukui seed shells.

The high chemical composition of oxygen in the shell reflects the presence of Lignin and Cellulose [21]. This affirms the natural composition test results carried out by [22] on the seeds shared in Table 8 :

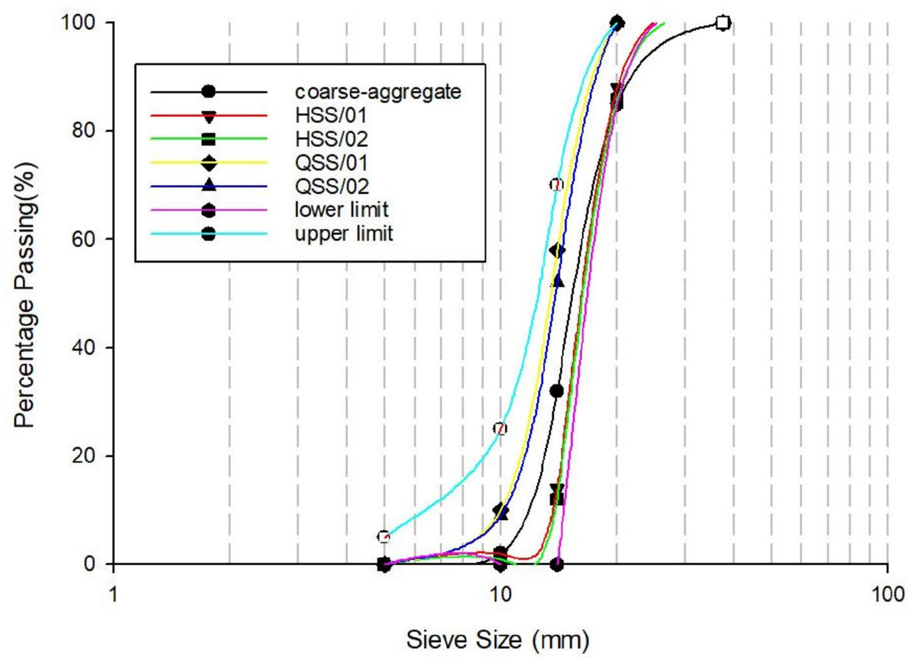


Fig. 15 Percentage passing Vs sieve size for Half Seed Shell and Quarter Seed Shell samples

Table 9 Grading check

Material	Coefficient of uniformity	Coefficient of uniformity	Comment
Coarse aggregate	1.41	0.96	Uniformly graded
Half seed shells	1.3	1.09	
Quarter seed shells	1.46	0.96	

Table 10 Maximum particle size

Material	Maximum Particle size (mm)
Coarse aggregate	20
Half seed shells	20
Quarter seed shells	14

3.1.1.3 Grading of Kukui seed shells Sieve analysis was done on the Quarter Seed Shells (QSS) and Half Seed Shells (HSS). Figure 15 shows the grading curve derived from the experiment.

Table 9 shows a grading check for the respective seed shells.

Table 10 shows the maximum particle size for the respective seed shells.

Both Quarter Seed Shells and Half Seed Shells are uniformly graded. They have a maximum particle size of 14 mm for the Quarter Seed Shells and 20 mm for the Half Seed Shells. An appropriate coarse aggregate with approximately similar grading 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).

3.1.1.4 Mechanical tests *Specific gravity*

Figure 16: Variation of kukui seed shells with Steel-Slag (ref), Talipot Palm Seeds (…), Pumice (…), Quarter Seed Shells, and Half Seed Shells.

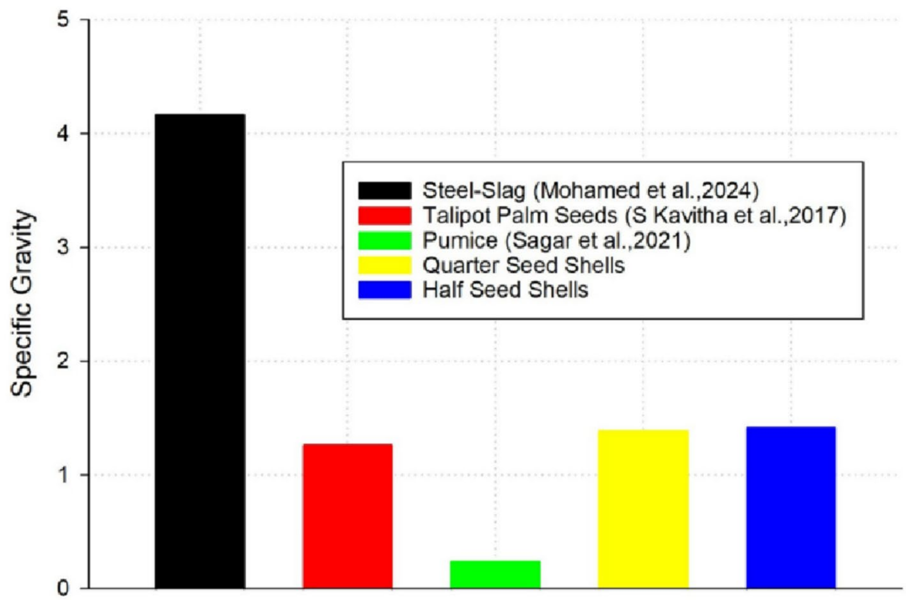


Fig. 16 shows the variation of specific gravity with different Light Weight Aggregates

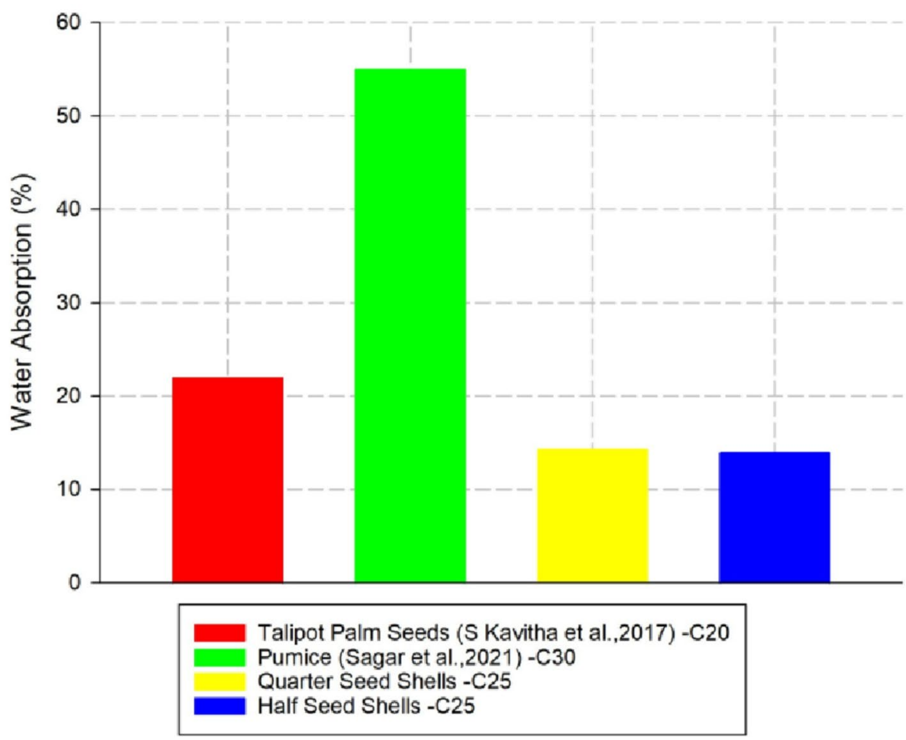


Fig. 17 shows the variation of water absorption values with different Light Weight Aggregates

It can be noted that the Kukui seed shells have a similar specific gravity to the Talipot palm seeds.

Water absorption

Figure 17: Variation of kukui seed shells with Talipot palm seeds, Pumice, Quarter seed shells, and half seed shells.

It can be noted that the Kukui seed shells have better water absorption properties compared to Talipot Palm Seeds and Pumice.

Other properties of the seeds

Table 11 shows the mechanical test output for the experiments carried out on the Kukui seed shells.

Kukui seed shells are classified as lightweight aggregates due to their low density (below 2000 kg/m^3). Despite their high-water absorption rates, which are attributed to lignin and cellulose content acting as moisture-retaining sponges [23]. These shells demonstrate satisfactory structural performance, with aggregate impact and crushing values well within recommended limits, owing to the rigidity imparted by their organic composition [24]. However, their flakiness indices are notably high, likely resulting from crusher motor speed settings, which can be optimized to improve aggregate shape [25]. Additionally, kukui seed shells show adequate abrasion resistance and soundness, reinforcing their potential use as sustainable lightweight aggregates, provided that mix designs address their porosity and shape irregularities.

Kukui shells are biomass materials composed primarily of lignin, cellulose, and extractives. This composition directly influences their physical and mechanical properties, which in turn affects concrete performance. The high lignin content typically contributes to lower density and greater stiffness of the shell particles, while the cellulose and hemicellulose fractions are associated with higher water absorption due to their hydrophilic functional groups [24]. These features scientifically explain the concrete behavior. For example, the lower density of Kukui Seed Shells contributes to an overall reduction in concrete unit weight, which aligns with trends reported for other biomass-based lightweight aggregates such as coconut shells and palm kernel shells [25].

3.1.2 Experimentation of Kukui seeds concrete

Tests were carried out on wet and dry concrete.

3.1.2.1 Tests on wet 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 and 60 mm as an ideal requirement. Table 12 shows the slump values for the different concrete partial replacement designs. The reduction in slump is mainly due to the increased percentage of highly absorptive aggregates [26]. This high absorption rate affects the water-cement ratio and causes lower slump values.

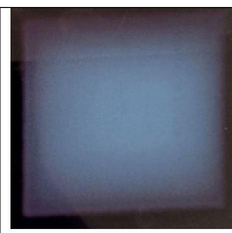
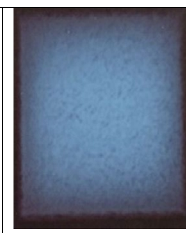
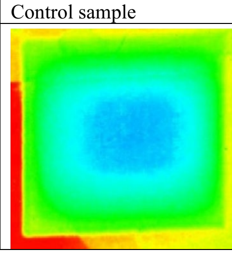
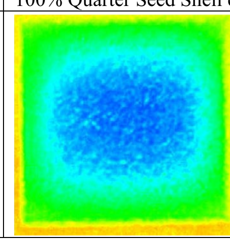
Table 11 Mechanical properties of Kukui seed shells, fine aggregates, and coarse aggregates

No.	Material property	Aggregate type				
		Coarse aggregates	Fine aggregates	Half seed shells	Quarter seed shells	Standard
1.	Density (kg/m^3)	2,637	2.598	1,421	1,394	2000
2.	Flakiness index (%)	32.5		95.3	60.3	40
3.	Aggregate impact value (%)	26.5		9.0	10.7	25
4.	Aggregate crushing Value (%)	22.2		15.2	14.1	30
5.	Los Angeles abrasion value (%)			16.7	17.6	30
6.	Soundness	0.43		1.14	4.12	6
7.	Silt content		3			4

Table 12 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

Table 13 Distribution of voids in control vs. 100% QSS sample

Before Image processing	 Control sample	 100% Quarter Seed Shell concrete
After Image Processing		

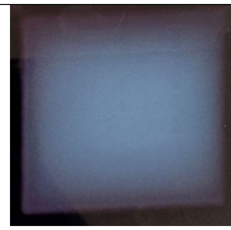
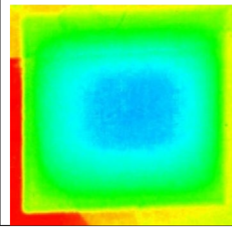
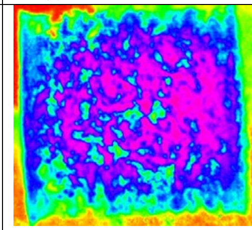
The slump test results show that replacing conventional aggregates with kukui shells reduces workability. The workability of the concrete reduces with an increase in the percentage of kukui seeds used [37–39]. This is primarily due to the high-water absorption (~ 14%) of the shells, which lowers the effective water–cement ratio. Additionally, their rough, porous surfaces and high specific surface area increase inter-particle friction and paste demand, while their low density and organic composition can affect mixture cohesion and flow. Collectively, these factors account for the observed slump reduction, consistent with previous findings for lightweight and bio-based aggregates [26].

Additionally, it has been acknowledged that the significant slump reduction observed in kukui seed shell concrete represents a limitation with respect to field applicability. The high-water absorption, porous microstructure, and hydrophilic lignocellulosic composition of the aggregates accelerate internal moisture uptake during mixing, leading to rapid slump loss and reduced cohesion. This requires water adjustment, admixture use, or preconditioning techniques. These factors complicate mix design and may limit large-scale construction applications without further optimization [24]. This limitation is now clearly stated in the discussion and conclusion sections.

3.1.2.2 Tests on dry concrete *Internal topography of the concrete cube*

The Digital Xray machine was used to scan the concrete cubes. ImageJ was used as an image processor to aid in interpretation of the voids within the cubes. Tables 13 and 14

Table 14 Distribution of voids in control vs. 100% HSS sample

Before Image processing	 Control sample	 100% Half Seed Shell concrete
After Image Processing		

show the distribution of air voids within the Quarter Seed Shell (QSS) concrete and Half Seed Shell (HSS) concrete respectively.

The experiment showed 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.

Effects of the above findings on the mechanical performance of the concrete

The mechanical behaviour of concrete containing shell aggregates is governed by the interaction between the cement paste and the shell particles, particularly at the interfacial transition zone (ITZ). Stress transfer occurs through a combination of bonding, friction, and mechanical interlock at the aggregate–paste interface. The shell's properties, such as its surface roughness and porosity, influence the efficiency of stress transfer. The smoothness of the shell and its porosity reduce bonding and may initiate microcracks, leading to low mechanical properties [25].

Density

Figure 18 shows the variation of the density of concrete cubes with an increasing percentage of Quarter and Half Seed Shells.

It was observed that as the percentage of Quarter Seed Shells (QSS) and Half Seed Shells (HSS) increased, the density of the concrete reduced. The density of the concrete reduces with an increase in the percentage of kukui seeds used [37–39]. There is a 21% reduction in density from the control mix to 100% QSS. Similarly, there is a 29% reduction in density from the control mix to 100% HSS. Generally, the use of HSS in the concrete leads to less dense concrete compared to using QSS. The lower densities in the HSS in relation to the QSS are attributed to the increased number of voids in the HSS compared to the QSS.

Compressive strength

The Fig. 19 shows the variation of compressive strength with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells reduce the compressive strength of concrete. The compressive strength reduces with an increase in the percentage of kukui seeds used [37–39]. Quarter Seed Shells performs better with 50%QSS and 25%QSS

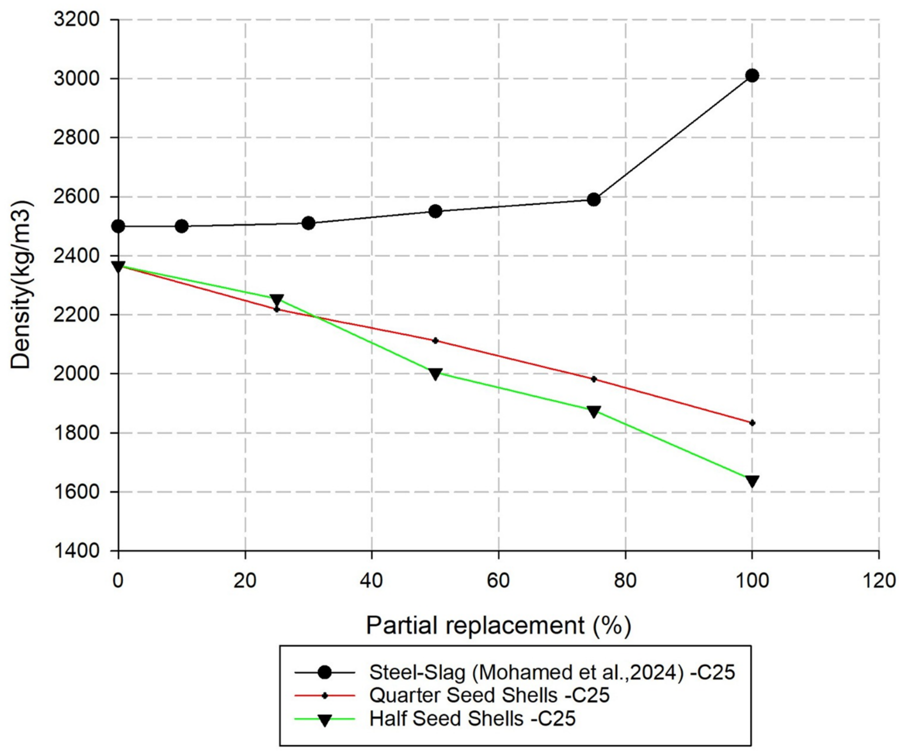


Fig. 18 Variation of densities of cubes with increased percentage of seed shells

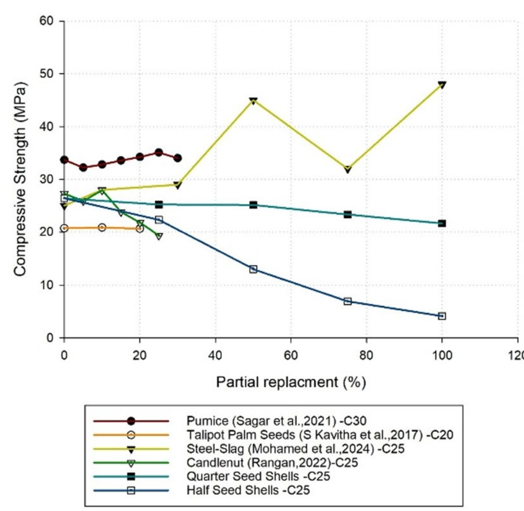


Fig. 19 Variation of Compressive strength, at 28 days, of cubes with increased percentage of seed shells

being above C25 after 28 days. One of the causes of the reduction in Compressive strength is due to the presence of voids. An increased number of voids in the Inter-facial zone in concrete reduces the compressive strength [27] Additionally, because 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, leading to air voids within the concrete [26].

Flexural strength

The Fig. 20 shows the variation of Flexural strength with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells reduce the Flexural Strength of concrete. There is a 96% and 91% reduction in Flexural Strength from the control mix to 100% Half Seed Shell and 100% Quarter Seed Shell concrete, respectively. The Quarter Seed Shell concrete performs better than the Half Seed Shell one. This reduction in Flexural Strength is due to poor bonding of the kukui seed shells within the concrete matrix. This is attributed to the smooth kukui seed shells surface [26].

Splitting tensile strength

The Fig. 21 shows the variation of splitting tensile strength with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells reduce the Splitting Tensile Strength of concrete. There is a 74% and 21% reduction in Splitting Tensile Strength from the control mix to 100% Half Seed Shell and 100% Quarter Seed Shell concrete, respectively. The Quarter Seed Shell concrete performs better than the Half Seed Shell one. This reduction in split tensile Strength is due to poor bonding of the kukui seed shells within the concrete matrix. This is attributed to the smooth kukui seed shells surface [26].

Modulus of elasticity

The Fig. 22 shows the variation of Modulus of Elasticity with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells reduce the Modulus of Elasticity of the concrete. There is a 92% and 67% reduction in Modulus of Elasticity from the control mix to 100% Half Seed Shell and 100% Quarter Seed Shell concrete, respectively. Quarter Seed Shell concrete performs better than Half Seed Shell concrete. The reduction in Modulus of Elasticity is due to the presence of voids. The increased number of voids in

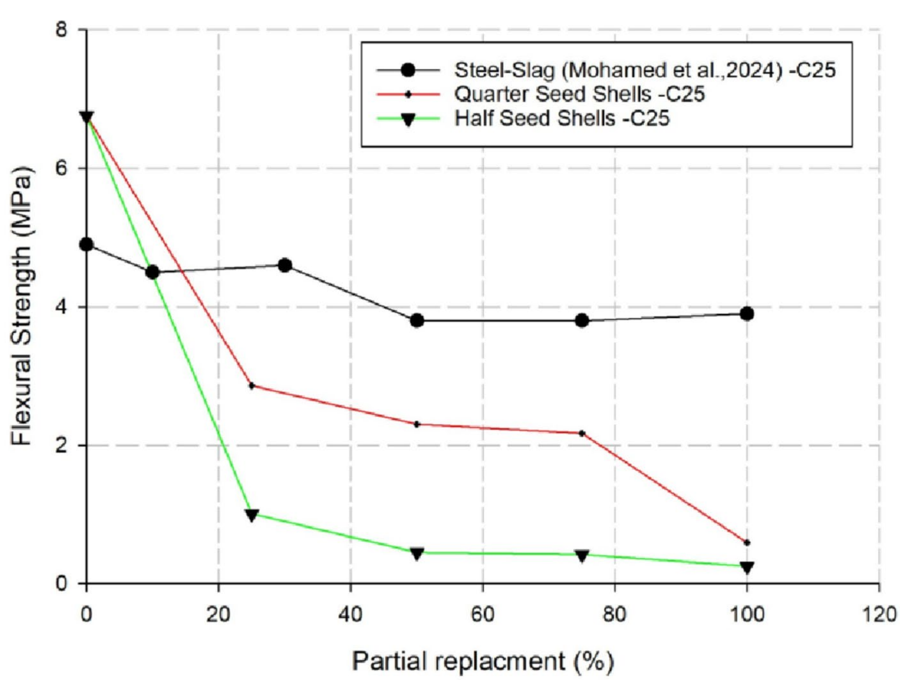


Fig. 20 Variation of flexural strength of beams with increased percentage of seed shells

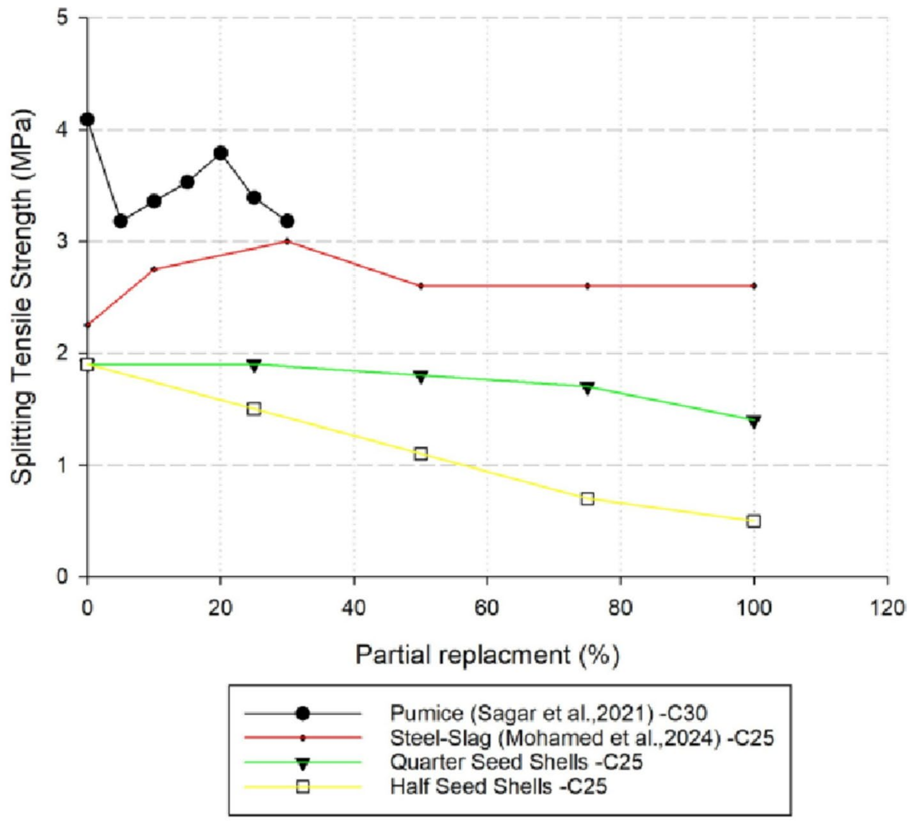


Fig. 21 Variation of splitting tensile strength of cylinders with increased percentage of seed shells

the Inter-facial zone in concrete reduces the compressive strength [27] hence reducing the Modulus of Elasticity of the concrete.

A steep decline in the modulus of elasticity for the concrete mix that consisted of Half Seed Shells can be attributed to microstructural weaknesses such as porosity. Due to the hollow hemisphere shape of the half seed shells, some of the cement paste or coarse aggregates will not be able to fill the void. This increases the percentage of voids in the concrete, hence greatly affecting its Modulus of Elasticity performance.

The respective statistical data value outputs for the results gotten from the effect of the partial replacement percentages on the Modulus of Elasticity of the concrete are shown in Table 15 :

There is a low standard deviation for both Quarter and Half Seed Shell concrete values for the Modulus of Elasticity at 28 days. A low standard deviation indicates the data points are closely packed, hence low dispersion and variability.

Durability tests

a. Water Absorption

The Fig. 23 shows the variation of water Absorption with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells increase the water absorption percentage of the concrete. There is a 332% and 120% increase in Water Absorption from the control mix to 100% Half Seed Shell and 100% Quarter Seed Shell concrete, respectively. Quarter Seed Shells perform better than Half Seed Shells. The increased number of

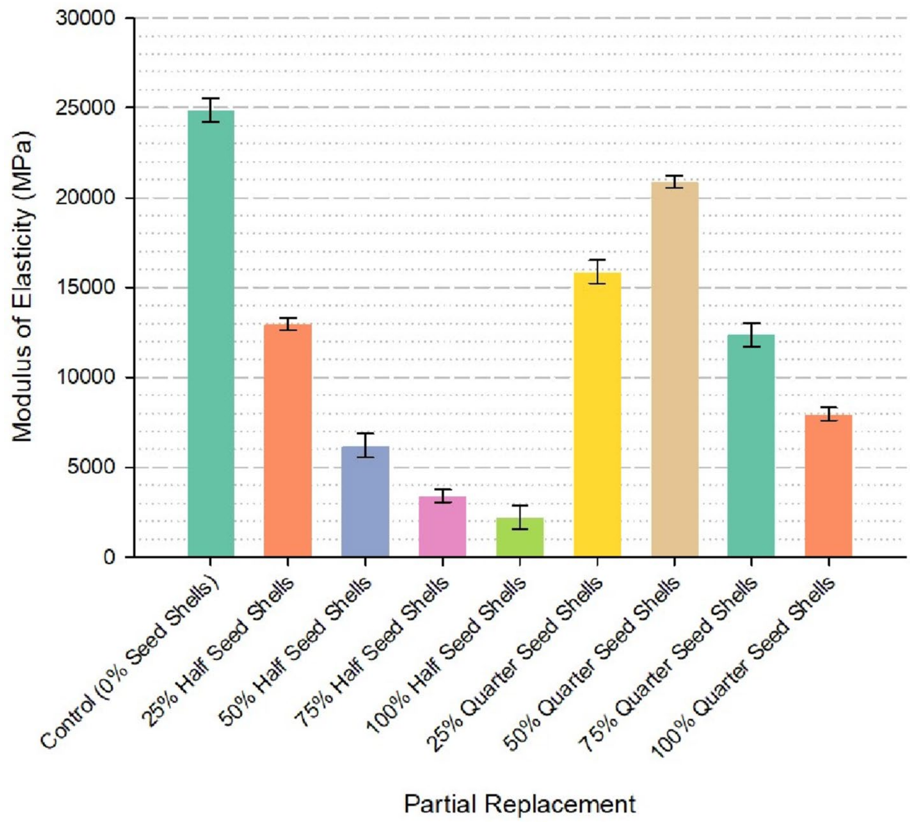


Fig. 22 Variation of Modulus of Elasticityof cubes with increased percentage of seed shells

Table 15 Statistical data for modulus of elasticity results

S/N	Sample	Standard deviation (%)	Mean (MPa)	Confidence interval (%)	
1	Control	536	24,873	24,873 ± 1333.98	Low standard deviation
2	25% quarter seed shells	289	12,966	12,966 ± 719	Low standard deviation
3	50% quarter seed shells	536	6213	6213 ± 1333.88	Low standard deviation
4	75% quarter seed shells	654	3050	3050 ± 1625	Low standard deviation
5	100% quarter seed shells	625	2138	2138 ± 1554	Low standard deviation
6	25% half seed shells	536	15,873	15,873 ± 1334	Low standard deviation
7	50% half seed shells	279	20,887	20,887 ± 693	Low standard deviation
8	75% half seed shells	539	12,383	12,383 ± 1341	Low standard deviation
9	100% half seed shells	288	7951	7951 ± 717	Low standard deviation

voids in the Inter-facial zone in concrete reduces the compressive strength [27] which increases pockets for water to be retained in.

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 Table 16 :

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, hence low dispersion and variability.

b. Thermal Conductivity

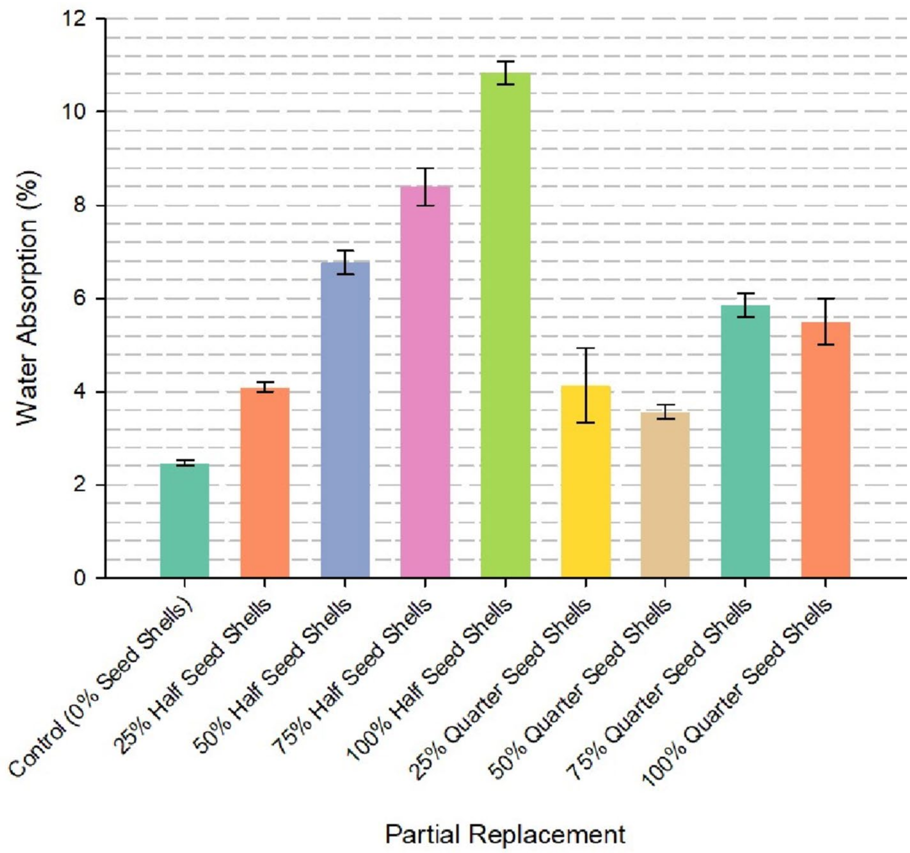


Fig. 23 Variation of Water Absorption of cubes with increased percentage of seed shells

Table 16 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

The Fig. 24 shows the variation of Thermal Conductivity with an increasing percentage of Quarter and Half Seed Shells.

Both Half Seed Shells and Quarter Seed Shells reduce the Thermal conductivity of the concrete. There is a 68% and 57% reduction in Thermal Conductivity from the control mix to 100% Half Seed Shell and 100% Quarter Seed Shell Concrete respectively. Half Seed Shells perform better than Quarter Seed Shells. The increased number of voids in the Inter-facial zone in concrete reduces the compressive strength [27] which increases air pockets, which reduce the transfer of heat within the concrete.

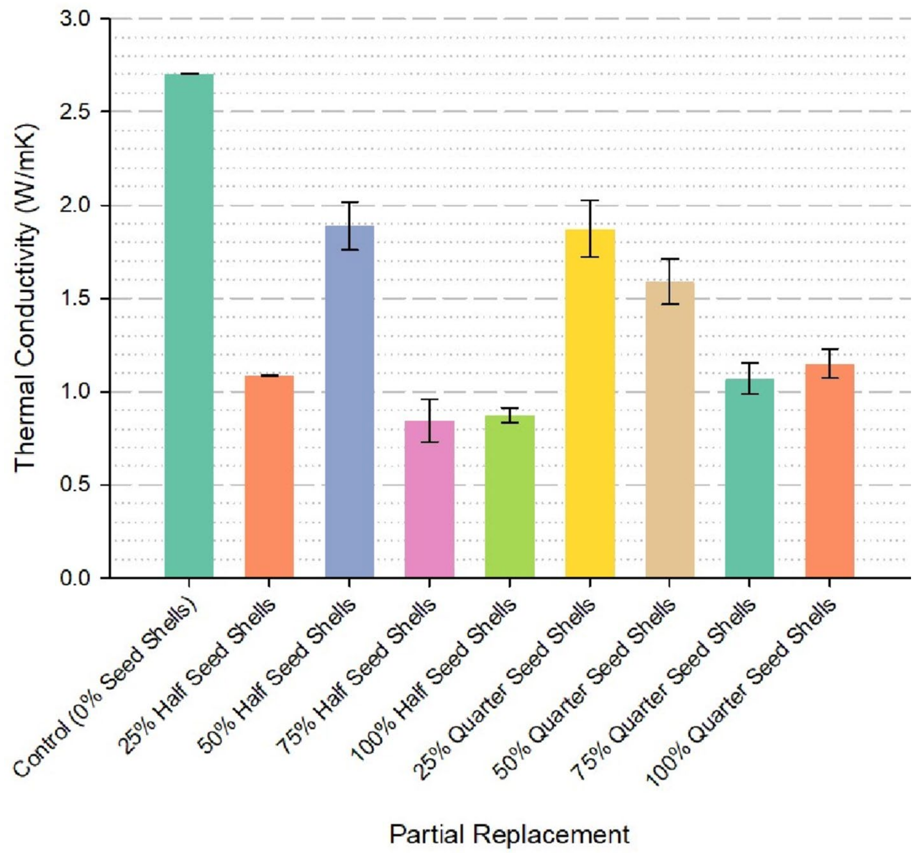


Fig. 24 Variation of Thermal Conductivity of cubes with increased percentage of seed shells

Table 17 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

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 Table 17 :

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, hence low dispersion and variability.

Effects of a low thermal conductivity on the mechanical properties of the concrete

The lower the thermal conductivity values, the higher the possibility that the concrete has voids, since the air pockets within the concrete hinder heat transfer. The higher the voids, the lower the mechanical performance of concrete, for example, it lowers the compressive strength. concrete [24].

c. Fire Resistance

The compressive strength of the concrete cube is measured before firing using a rebound (Schmidt) hammer. Thereafter, in the fire resistance test, the cube is fired until a temperature of 250 °C in a ceramic kiln for 8 h [28]. Normally, the cubes are removed, and their compressive strength is measured. Unfortunately, both the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) disintegrated when removed from the kiln. Figure 25 shows the graph showing the temperature, vs. compressive strength ratio 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 26 shows the state of the Half Seed Shells (HSS) and Quarter Seed Shells (QSS) after firing. The specimen failed the fire resistance test.

Effect of firing on organic aggregates

Kukui seed shells, like other lignocellulosic materials, consist primarily of cellulose and lignin, each of which decomposes at different temperature ranges. Cellulose decomposes at approximately 280–350 °C while lignin degrades more gradually over a wider temperature range (250–500 °C) [27]. These decomposition processes release volatiles and lead to mass loss, weakening the structural integrity of the aggregate and contributing to reduced strength retention in concrete subjected to fire conditions. The formation of a char layer can provide partial thermal insulation but may also disrupt aggregate to

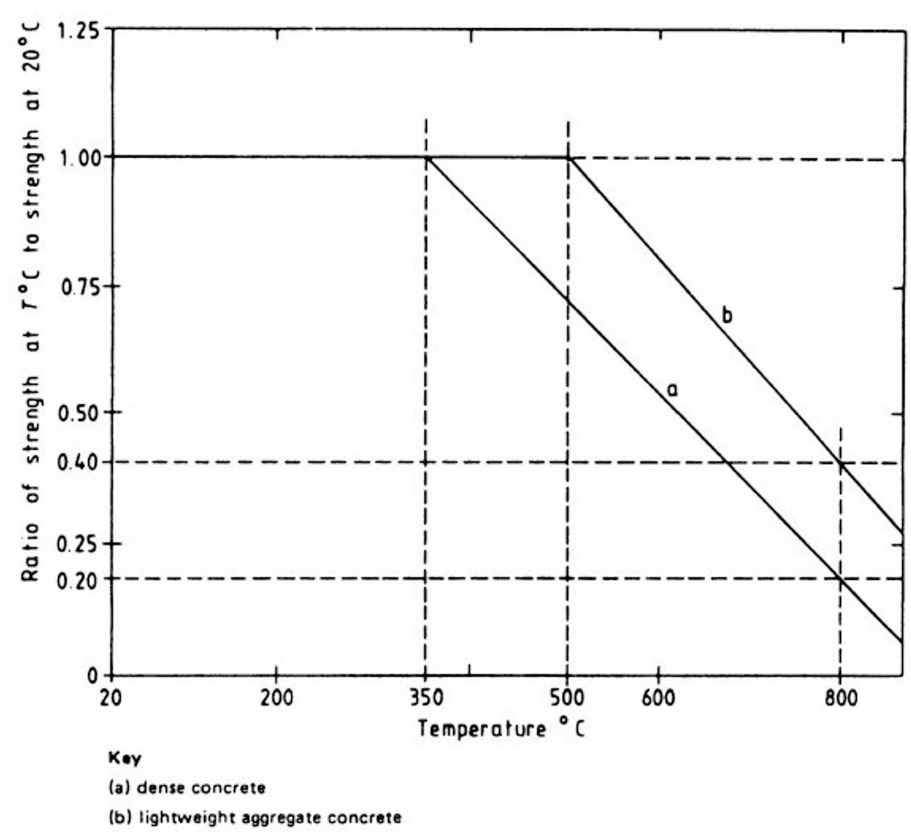


Fig. 25 Design curves for variation of concrete strength with temperature (BS8110-2:1985)

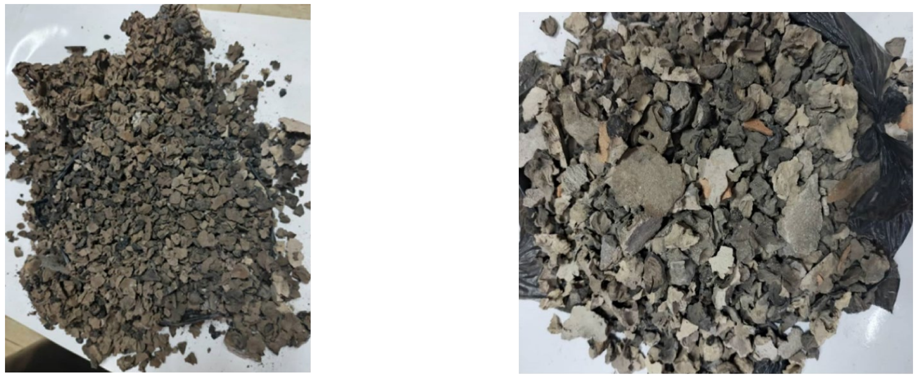


Fig. 26 100% QSS and 100% HSS after being fired at 250 °C for 12 h

cement adhesion due to shrinkage, cracking, or collapse of the organic structure [28]. As the internal voids of the kukui seed shells heat up, the trapped air may expand, intensifying microcracking within the interfacial transition zone (ITZ), further reducing post-fire mechanical performance. These mechanisms align with observations from studies on organic aggregate concretes such as coconut shell or palm kernel shell concretes, which also exhibit significant thermal degradation linked to biomass decomposition [27].

After execution of mechanical tests on concrete, it was observed that:

Generally, it was observed that the high water absorption exhibited by the kukui seed shell aggregates is directly attributable to their elevated internal void content, a characteristic typical of lignocellulosic lightweight aggregates. Materials with greater porosity possess a larger volume of interconnected capillaries and microvoids, which facilitate rapid penetration and retention of water through capillary suction and adsorption mechanisms [23]. Studies on similar organic aggregates, such as coconut shells and palm kernel shells, show that high open-porosity values (often exceeding 20–30%) correspond to significantly higher water absorption capacities, frequently above 15% by mass [28]. These trends align with the microstructural characteristics of Kukui Seed Shells, whose porous internal structure, resulting from the natural arrangement of lignin and cellulose, promotes substantial uptake of water. Therefore, the observed water absorption behavior is quantitatively consistent with the expected relationship between porosity and moisture uptake in lightweight organic aggregates, reinforcing the interpretation rather than relying solely on visual or qualitative evidence.

Additionally, while voids and surface texture are indeed influential factors in lightweight aggregate concretes, we now support these interpretations with measurable parameters such as aggregate porosity, water absorption, and estimated interfacial transition zone (ITZ) characteristics. For example, the high porosity of organic aggregates like kukui seed shells has been shown to correlate with weaker ITZ bonding, thereby contributing to reductions in compressive strength and modulus of elasticity [29] Additionally, smooth textured organic aggregate surfaces often exhibit reduced mechanical interlocking, but this effect is now discussed alongside quantitative data on absorption capacity and density, which influence the effective stress transfer between the aggregate and cement matrix [29]. By incorporating these measurable properties, the revised discussion avoids repetitive narrative explanations and provides a more rigorous,

Table 18 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	

Table 19 ANSYS beam deformation output

No.	Material	Deflection due to point load (mm)			
		5,000 *N*	10,000 *N*	15,000 *N*	20,000 *N*
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

microstructure-informed interpretation of the mechanical performance of kukui seed shell concrete.

3.1.2.3 Numerical analysis *Engineering constants*

When developing the model in ANSYS, the program prompted for engineering constants to aid in its analysis. Table 18 shows the mechanical properties used as engineering constants during the simulation process.

Serviceability performance output from ANSYS

The different deformation outputs for the different loads on the different beams that were developed for the simulation are shown in Table 19 .

After analysis of the results, Fig. 27 was developed using the loads that the Quarter Seed Shell (QSS) and Half Seed Shell (HSS) are at in order to reach the desired maximum deformation of 10 mm. Readings from 100% to 25% Half / Quarter Seed Shells and the control concrete (100%CA) were used.

It was observed that there is a 91% and 67% reduction in the Load required to reach the 10 mm deformation from the Control concrete to 100% Half Seed Shell Concrete (HSS) and Quarter Seed Shells (QSS) respectively.

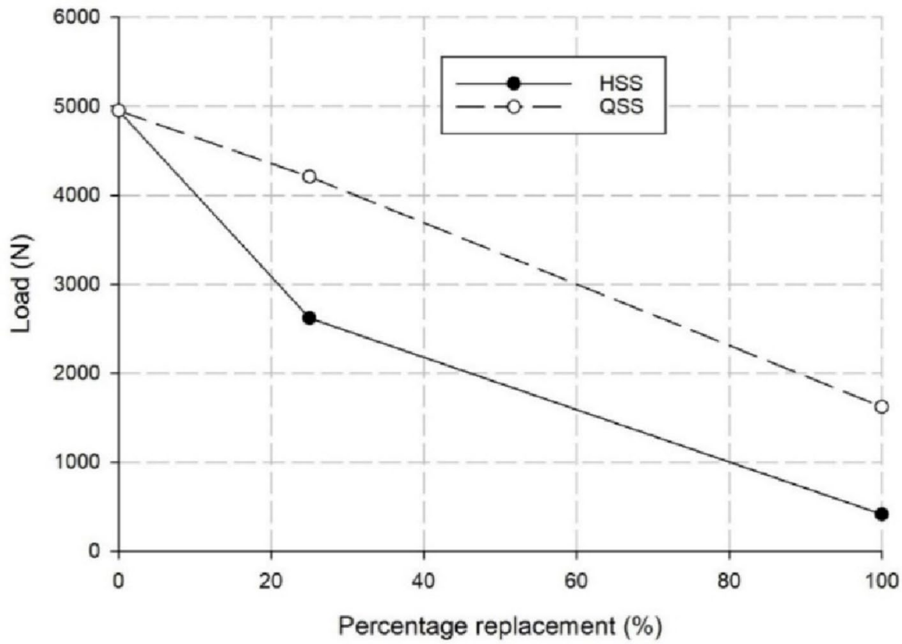


Fig. 27 Variation of load for 25%and 100% quarter (QSS) and half (HSS) seed shells at 10 mm deformation

4 Conclusions

The main objective of this study was to investigate the performance of kukui seed shell size and replacement percentage as a 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 carried out 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 their 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, 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 kukuiseeds (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 compared to the Half Seed Shell concrete to reach the maximum deflection. This was determined after analysis of ANSYS results.

Generally, Quarter Seed Shells perform better than Half Seed Shells in concrete due to their better packing density and reduced voids within the concrete. These properties greatly improve the performance of its concrete during mechanical testing.

4.1 Recommendations

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

Limitations of the study

a. The study was limited to a maximum aggregate size of 20 mm, which is recommended for reinforced concrete.
b. 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.
c. The study was limited to a concrete grade of C25. It does not consider the effects of the kukui seed shells on other grades of concrete.
d. This study has not considered the economic aspect of using the kukui seed shells due to a lack of data to aid in assessing cost.

Kukui seed shell contribution to sustainable construction:

a. Using kukui seed shells supports the use of local and renewable materials.
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, reduces the overall self-weight of a structure, which reduces the need for complex foundations to support the structure.
d. Kukui seed shell extraction and production process has a positive impact on the livelihood of the community taking part in the process by providing 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:

a. 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.
b. Thermal and acoustic insulation: Due to its good thermal conductivity values, it can be used to insulate roof screed and provide both acoustic and thermal insulation for internal wall panels.
c. Medium strength structural elements: With the addition of some admixtures to improve on some properties like flexural strength, the concrete can be used in some structural elements like lintels.

d. 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 reducing carbon footprint.
e. Internal curing applications: In areas where mass concrete is used, the internal curing properties reduce cracking and improve the performance of concrete exposed to early-age thermal gradients.
f. Coarse aggregate in three-dimensionally printed concrete [34]: This is a new innovation in construction that should be exploited. Kukui seed shells are lightweight, renewable, and can be processed to suitable particle sizes. They reduce reliance on natural aggregates while improving sustainability and potentially enhancing the printability and material efficiency of three-dimensionally printed concrete.

Other areas of study that should be explored include:

a. 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.
b. Water Absorption treatment for highly absorptive aggregates (Light Weight Aggregates).
c. Reduction of air voids in Quarter Kukui Seed Shell concrete.
d. The evaluation of the use of Eighth Kukui Seed Shells as a material replacement for Fine Aggregates.
e. The effect of the use of CEM 1 cement on the properties of concrete that uses kukui seed shells as coarse aggregates.
f. Design an appropriate crushing mechanism for crushing the kukui seed shells that reduces the flakiness of the shells.
g. Fire resistance of Organic Light weight Aggregate.
h. The determination of the optimum water–cement ratio for concrete containing partial replacement of coarse aggregates with kukui seed shells.
i. Addition of paper mill lime sludge waste as a partial replacement of cement in kukui seed shell concrete. It was noted that a 15% partial replacement of cement with paper mill fly ash improves the flexural strength of the concrete by 16% [35]. The combined use of these materials (paper mill fly ash and kukui seed shells) promotes waste valorisation and contributes to sustainable construction by reducing reliance on virgin raw materials while improving concrete properties.

Author contributions
B.A, K.M and S.V were fully involved during execution of the study.

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Data availability
The data that supports the findings of this study are available in the supporting information of my manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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