International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-13 Issue-4, April 2024

Structural Performance of Reinforced Concrete Slab with Sugarcane Bagasse Ash and Plastic Flakes as Partial Replacement

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Abstract**: *This research aims to reduce the weight of concrete structural members and promote the use of eco-friendly concrete. To achieve this, plastic flakes and sugarcane bagasse are used as additional materials in concrete production, which can partially replace fine aggregates and cement respectively. This makes structural members lighter, reducing the overall load transmitted to the foundation and the construction cost. The study investigates the effect of plastic flakes and sugarcane bagasse ash on the performance of a reinforced concrete slab. It includes workability, compressive, flexural, tensile strengths, and water absorption of different mix proportions in the fresh state. Various sugarcane and plastic flake percentage replacements of cement and fine aggregates are also investigated. The results show that the 5% SCBA and 5% plastic flake replacement ratio has better mechanical properties compared to the control concrete and other mix ratios. This ratio is used in casting the reinforced concrete slab, whose structural behavior is then investigated in terms of ultimate load, ultimate deflection, load-deflection relationship, and crack patterns. The study shows that the incorporation of sugarcane bagasse ash and plastic flakes as partial replacements improves the bearing of ultimate load capacity. Still, the slab portrays higher deflection than the control slab. The crack patterns appear in the tension zone of the slab, and the slab fails in flexion.***

Keywords**: *Structural Performance, Concrete, Sugarcane Bagasse Ash (Scba), Plastic Flakes, Ordinary Portland Cement.***

I. INTRODUCTION

Most underdeveloped and developing countries' economic growth has increased construction sector activities. The importance of providing housing as a basic need and constructing advanced commercial buildings is now being recognized in many countries. Cement and fine aggregates are extensively used in the construction industry for producing concrete, mortar, precast elements, and building blocks [1][35][36].

Manuscript received on 13 February 2024 | Revised Manuscript received on 20 February 2024 | Manuscript Accepted on 15 April 2024 | Manuscript published on 30 April 2024.
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The importance of providing housing as a basic need and constructing advanced commercial buildings is now being recognized in many countries. Cement and fine aggregates are extensively used in the construction industry for producing concrete, mortar, precast elements, and building blocks [1].

The proper management of solid waste is a pressing issue in the modern world and is a significant contributor to environmental deterioration. Waste materials such as sugarcane bagasse and plastic require effective disposal methods. Studies have demonstrated that recycling them as construction materials is a viable solution to their disposal problem.

Cement is a commonly used construction material that acts as a binder in concrete, resulting in a sturdy material that can withstand heavy loads [4]. However, the production of cement requires a significant amount of energy, generates dust, and is responsible for 5% of global carbon dioxide (CO2) emissions caused by human activity [5]. Sand is also an essential construction material, with river sand being a popular choice because the flowing water removes the weak and dissolvable sand fragments, leaving only the stable ones [6]. Despite its popularity, sand mining in rivers has negative impacts beyond the mining site, which has led to the search for alternative construction materials that can replace sand.

In reference [7], the physical properties of OPC and SCBA were compared and it was discovered that the distribution of SCBA particle sizes was times finer than that of OPC and that particles of sugar cane bagasse ash were more uniformly distributed. Sugarcane bagasse ash has a characteristic chemical composition to be generally categorized under class F pozzolan material based on ASTM C618 specification [8], [9]. In reference [2], and [7], sugarcane bagasse was used as a partial replacement for cement, and concrete mechanical and durability properties were determined. It was observed that bagasse ash is a pozzolanic material and improves concrete properties when at 10% replacement, a similar observation was observed in [10].

Reference [11] investigated the workability, unit weight, and compressive strength of concrete containing shredded Plastic waste as a partial replacement of 10 to 50%. It found that increasing PET content negatively affected the workability of the mixture, as evidenced by a slump value of 10 mm for the 50% PET concrete specimens. Reference [12][34] replaced 5 to 15% fine aggregates with plastic flakes which improve concrete toughness and compressive strength with increased plastic content.

A. General Objective

To assess the structural performance of reinforced concrete slab with sugarcane bagasse ash and plastic flakes as partial replacement of cement and sand.

a. Specific Objectives

i. To characterize the constituent materials (i.e., sugarcane bagasse ash, plastic flakes, fine and coarse aggregates, reinforcement, water, and cement) for use in the production of a reinforced concrete slab.
ii. To determine the effect of sugarcane bagasse ash and plastic flakes on the physical, mechanical, and durability properties of concrete.
iii. To assess the structural performance of the reinforced concrete slab with sugarcane bagasse ash and plastic flakes as a partial replacement.

B. Research Significance

The study is carried out to improve the mechanical and durability properties of reinforced concrete slabs by incorporating sugarcane bagasse ash and waste plastic flakes to replace cement and natural sand partially. Incorporating SCBA and plastic flakes to construct a slab is an economical way of construction due to the reduced quantity of the conventional materials used. The added materials are lightweight compared to the conventional ones, which reduces the self-weight of the structure as a whole and this building is easy and adaptable.

II. MATERIALS AND METHODS

The study utilized plastic bottles, aggregates, sugarcane bagasse ash, cement, water, river sand, and plastic flakes that passed through a 5 mm sieve. Type 1 cement conforming to [13] was used in the research. The size distribution of particles in sugarcane bagasse ash and cement was measured using a hydrometer analysis test. Their chemical composition was determined with a gravimetric method. To identify the mineral composition of sugarcane bagasse ash, X-ray diffraction (XRD) was used while its morphology was analyzed under a scanning electron microscope (SEM).

Trial tests are carried out on all batches using water-cement ratios of 0.4, 0.5, and 0.6. OPC and SCBA are mixed in various ratios of 0%, 10%, 15%, and 20% (as shown in Table 1). The prepared plastic flakes of 0%, 10%, 15%, 20%, and 25% by weight are blended with river sand (as shown in Table 2). The combination of plastic flakes and SCBA is added to concrete in different proportions of 5% SCBA and 5% plastic flakes, 5% SCBA and 10% plastic flakes, 10% SCBA and 10% plastic flakes, 10% SCBA and 5% plastic flakes, 10% SCBA and 15% plastic flakes, and 10% SCBA and 20% plastic flakes (as shown in Table 3).

The slab's deflection is measured with an LVDT. Strain gauges determine deformation in the reinforcement and concrete.

Table 1: Shows the Mix Proportions of Scba Partially Replacing Cement

Mix	SCBA	cement	SCBA	Water	FA	CA	W/C
No.	(%)	(kg/m³)					ratio
1	0	311.50	0.000	190	751.9	976.64	0.6
2	10	280.35	31.15	190	751.9	976.64	0.6
3	15	264.77	46.72	190	751.9	976.64	0.6
4	20	249.20	62.30	190	751.9	976.64	0.6

Table 2: Shows the Mix Proportions of Pet Flakes Partially Replacing Fine Aggregates

Mix	PET	cement	PET	Water	FA	CA	W/C
No.	(%)	(kg/m³)					ratio
1	0	311.500	0.000	190.000	751.967	976.64	0.60
2	5	311.500	37.598	190.000	714.368	976.64	0.60
3	10	311.500	75.197	190.000	676.770	976.64	0.60
4	15	311.500	112.795	190.000	639.172	976.64	0.60
5	20	311.500	150.393	202.475	601.573	976.64	0.60
6	25	311.500	187.992	202.475	563.975	976.64	0.60

Table 3: Shows the Mix Proportions of Scba Replacing Cement and Pet Flakes Partially Replacing Fine Aggregates

Mix	SCBA	PET	cement	SCBA	PET	Water	FA	CA	W/C
No.	(%)	(%)	(kg/m³)						ratio
1	0	0	311.50	0.00	0.00	190	751.96	976.64	0.6
2	5	5	295.92	15.57	37.59	190	714.36	976.64	0.6
3	5	10	295.92	15.57	75.19	190	676.77	976.64	0.6
4	10	10	280.35	31.15	75.19	190	676.77	976.64	0.6
5	10	5	280.35	31.15	37.59	190	714.36	976.64	0.6
6	10	15	280.35	31.15	112.79	190	639.17	976.64	0.6
7	10	20	280.35	31.15	150.39	190	601.57	976.64	0.6

III. METHODOLOGY

The study was carried out according to the flow chart, in Figure 3. Materials were collected, prepared, characterized, and used to prepare the test samples. The samples were tested as described in the following sections

A. Concrete Batching, Mixing, Moulding and Curing

The concrete of class 25 is prepared in the laboratory. The batching procedure involves weighing all the individual material fractions according to the mix design calculations. These fractions include water, fine and coarse aggregates, OPC, plastic flakes, and sugarcane bagasse ash. A rotating drum mixer is used for mixing the dry materials for 5 minutes before continuing for an additional 2 minutes. The calculated mixing water is then added to the dry mixture, and the paste is filled in cleaned and oiled moulds of cubes, cylinders, and slab in three (3) layers using a poker vibrator until the cement slurry appears on top of the moulds. The specimens are then left in the mould covered with a wet sackcloth for 24 hours. Open-air curing is done for 24 hours, after which the specimens are demoulded and placed in curing tanks containing clean water. For the slab, a wet thick blanket is covered on top of the specimen, and this is done 3 times a day for 28 days.

B. Workability

The slump cone and compaction factor test Figure 1 a), is conducted on each fresh mix batch to assess the behavior of the paste with various material replacements on the concrete's workability and consistency [14].

C. Compressive Strength

A universal compression testing machine with a load capacity of 150 metric tons is used to test 100mm cube samples of concrete.

After a specified period, the concrete samples are removed from the curing tank, wiped dry using a soft cloth, and air-dried for an hour. Subsequently, each sample is placed centrally between the battens of the compression testing machine. The top batten is brought into contact with the top surface of the sample, and load is applied at a constant rate until the cube is crushed. The maximum load attained is then recorded. Tests are carried out at 7 and 28 days, and 3 cubes are tested to obtain an average value for each record. The tests are carried out about [15].

D. Split Tensile Strength

Split tensile strength test is carried out at 28 days to [16]. 3 cylinders of 100-mm-dia. and 200-mm-long are tested for each mix and the average value is recorded.

E. Flexural Strength

Flexural strength test is carried out at 28 days according to [17]. 3 prisms are tested for each mix and the average value is recorded.

F. Water Absorption

A water absorption test is carried out at 28 days according to [18]. 3 cubes are tested for each mix and the average value is recorded.

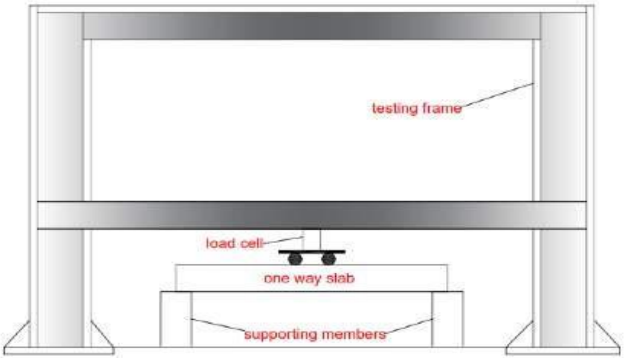
G. Design and Structural Analysis of Reinforced Slab

Two types of one-way slabs are tested by reference [19]. The first type is a control slab, while the second type contains 5% SCBA (spent coffee bean ash) and 5% plastic flakes. Each type is tested twice. The slab dimensions are 1500 x 700 x 150 mm, with main bars spaced at 150mm intervals and transverse bars spaced at 250mm intervals. A four-point load is applied to the slab using a hydraulic jack with a 2500KN capacity. The maximum deflection of the slab is measured using an LVDT. Strain gauges are used to measure the ultimate compressive, tensile, shear, and flexural strains exerted on the specimens. All slabs are loaded to their ultimate capacity.

Part A **Part B**

Figure 1: a) Workability Determination and b) Casted Concrete Cubes and Cylinders

Part A



Part B

Figure 2: Part A, the Casting of a one-way slab, and Part B, the Experimental Setup of Loading the Reinforced Slab

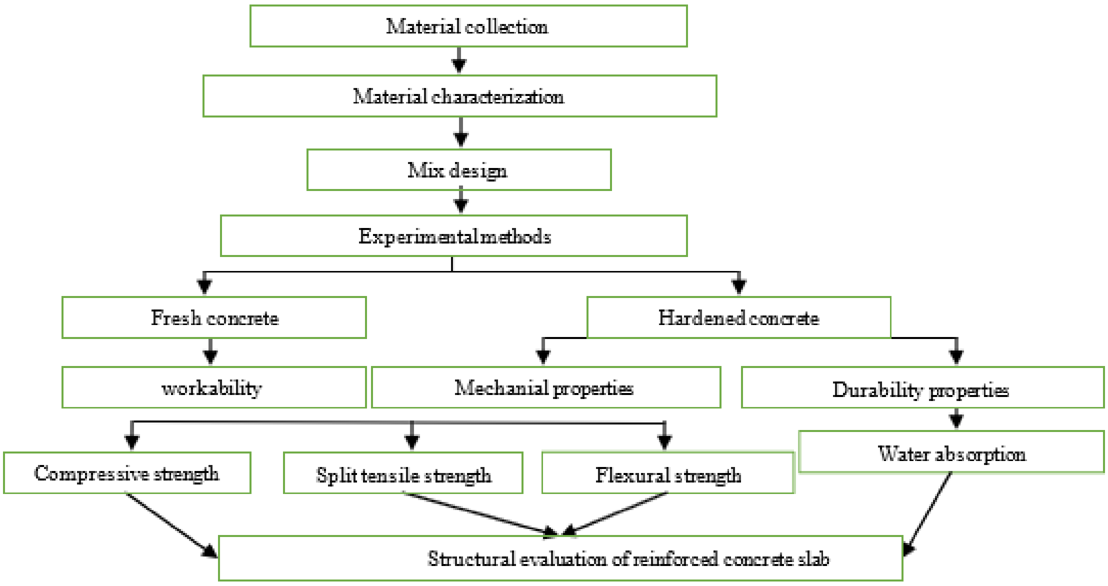


Figure 3. Flow Chart Showing the Methodology of the Study

IV. RESULTS AND DISCUSSIONS

A. Constituent Material Properties

a. Particle Size Distribution

The particle size distribution of SCBA is found to be finer than that of cement which is the same observation by [20] as shown in Figure 4A. The particle size of fine aggregates (sand and plastic flakes) used in the study ranges from 0.15mm to 5mm.

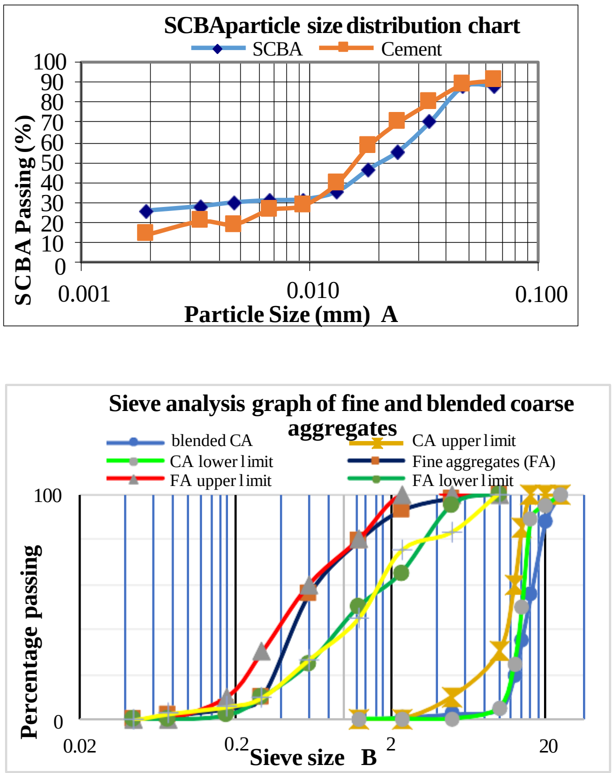


Figure 4: Particle Distribution of Sugarcane Bagasse and Cement, Part A and of Plastic Flakes, Fine and Coarse Aggregates

The maximum of the coarse aggregates was 20mm. The particle size distribution of aggregates and their grading limits, figure 4B are determined using the sieve analysis method according to [21].

b. Chemical Composition, XRD, and SEM Analysis

The primary oxide found in SCBA was Silica (SiO) which accounted for 73.949% of the total as shown in Table 4. Sugarcane bagasse ash was equally analyzed using X-ray diffraction (XRD) to characterize the mineral composition, figure 5. The results indicate the presence of large amounts of quartz and cristobalite in SCBA which was equally identified by [7]. In addition, the sample was tested using the scanning electron microscope (SEM) to show its morphology Figure 6. These observations are to that reported in [22].

Table 4: Percentage of Chemical Composition for SCBA and OPC CEM I 42.5N

Element name	Reference Specifications	SCBA (%)	Cement (%)
MgO	Not more than 3.0	3.159	0.84
Al O	Not more than 8.0	10.864	5.098
SiO	-	73.949	20.84
Fe O	-	3.636	3.24
K O	-	3.504	0.49
CaO	-	3.391	63.23
LOI	Not more than 5.0	4.9	3.1

Legend: LOI – Loss of Ignition

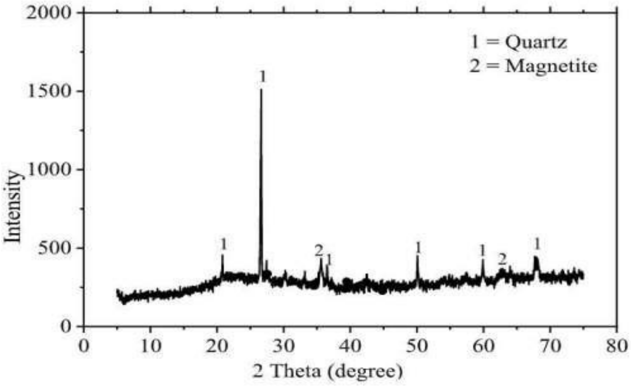


Figure 5: XRD (X-ray Diffraction) Analysis of Sugarcane Bagasse Ash

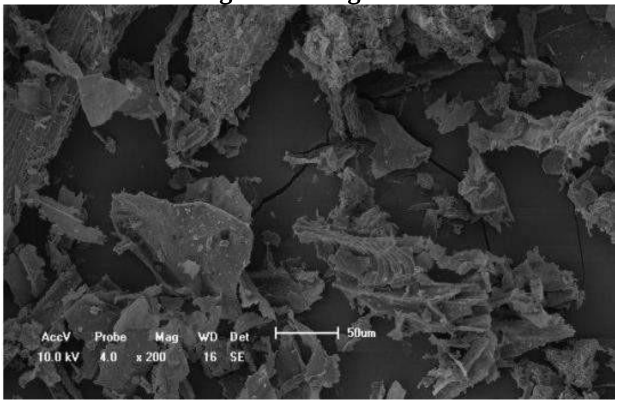


Figure 6: SEM (Scanning Electron Microscope) Analysis of Sugarcane Bagasse Ash

c. Workability

Previous studies have pointed out that the water demand increases with increasing SCBA replacement ratio in concrete, which decreases workability as reported by [4] and [23]. However, some studies have observed an improvement in workability which is attributed to the low value of LOI of SCBA as reported in [24] which indicated that SCBA is low in carbon content.

Figure 7A shows the slump value for all concrete mixes at different SCBA contents. It is observed that the slump decreases with an increase in SCBA content. This can be attributed to the flaky shape, rough texture, and porosity of SCBA grains, as can be observed from SEM images. The workability of concrete with plastic flakes as partial replacement of fine aggregates is equally observed to reduce as the ratio of replacement increased as shown in Figure 7B. The same conclusion is observed in the previous studies [25], [26] and [27]. The workability of concrete with SCBA and plastic flakes, figure 7C for all mixes was lower than that of the control mix. The mix with 10% SCBA and 20% plastic flakes replacement portrayed the lowest slump value with a percentage reduction of 30.76%. The subsequent percentage reductions recorded are 2.56%, 12.82%, 20.51%, 15.38%, 23.08%, and 30.77% for the 2, 3, 4, 5, 6, and 7 mix proportions.

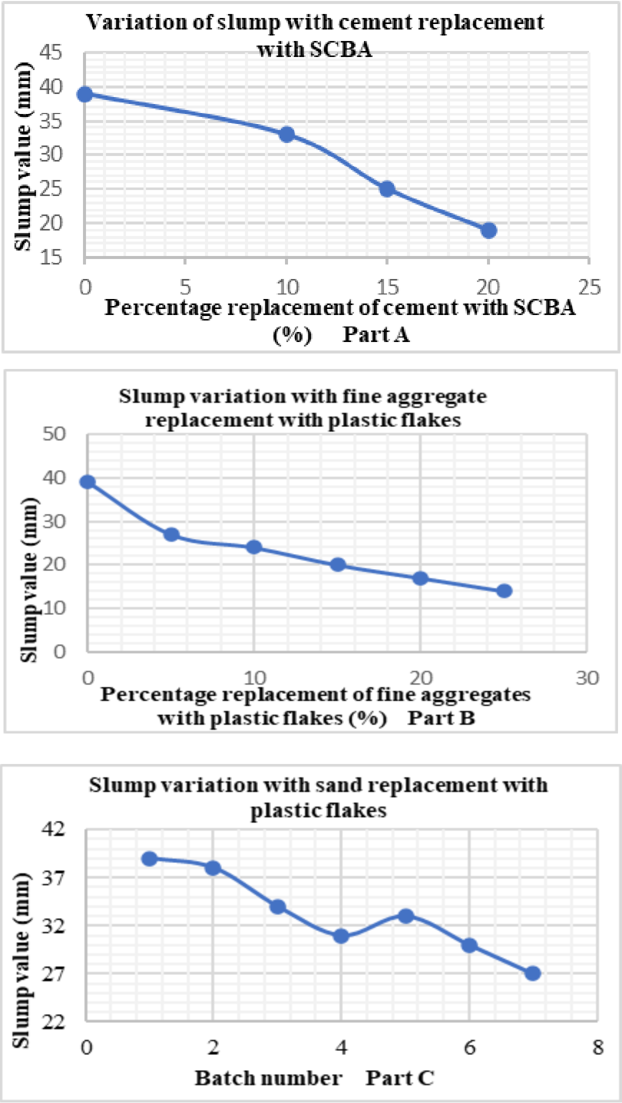


Figure 7: Effect of Part A, SCBA Replacement of Cement; Part B, Plastic Flakes Replacement of Fine Aggregates; Part C, Scba and Plastic Flakes Replacement of Cement and Fine Aggregates on the Workability of Concrete Slump Test Results

d. Compressive Strength

Compressive strength for all mixes of concrete increased with curing time which was equally observed by [2], [25], [26], [28], and [29]. Figure 8A shows a comparison of compressive strength results of all mixes according to different mix proportions of SCBA and curing at 7 and 28 days. The 28-day compressive strength values were greater than those at 7 days for all the percentage replacements of cement with SCBA. The compressive strength of concrete at 7 and 28- days of curing time increased for 10% replacement and then decreased with increasing percentage from 15% replacement of cement with the SCBA. Similar behavior was observed in various studies [30], [31]. Compressive Strength of the SCBA concrete blends increased by 16.90% with 10% replacement of cement with SCBA and decreased at percentages of 8.04% and 14.85% for 15% SCBA and 20% SCBA respectively at 28 as compared with the control mix.

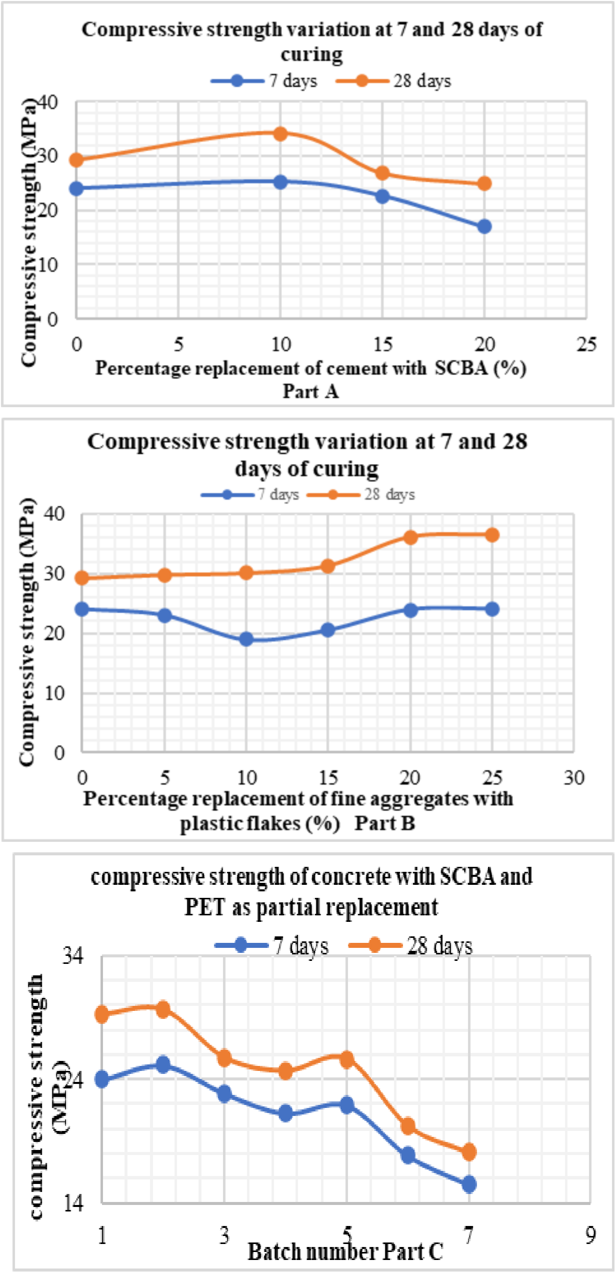


Figure 8: Effect of Part A, SCBA Replacement of Cement; Part B, Plastic Flakes Replacement of Fine Aggregates; Part C, SCBA and Plastic Flakes Replacement of Cement and Fine Aggregates on the Compressive Strength of Concrete

The compressive strength of concrete is tested at both 7 days and 28 days for the various plastic flake additions of 5%, 10%, 15%, 20%, and 25% of the weight of cement compared to the control mix (without plastic flakes) as shown in figure 8B. At 7 days, a reduction in compressive strength is recorded for all percentage replacements except that of 25% replacement that portrayed similar compressive strength as that of the control mix. A study carried out by [32], observed an increase in compressive strength with increasing plastic flake ratio from 10 to 30% beyond which the strength started decreasing.

Published By:
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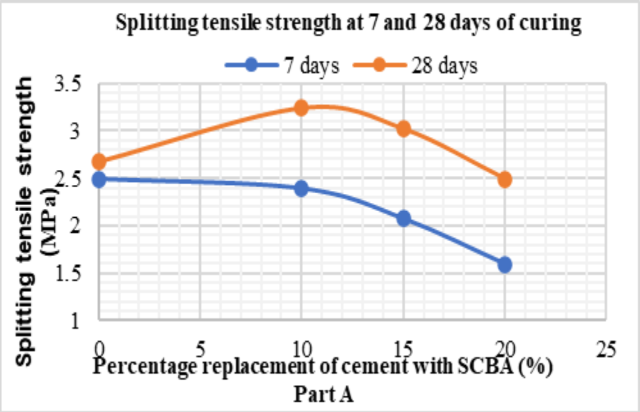
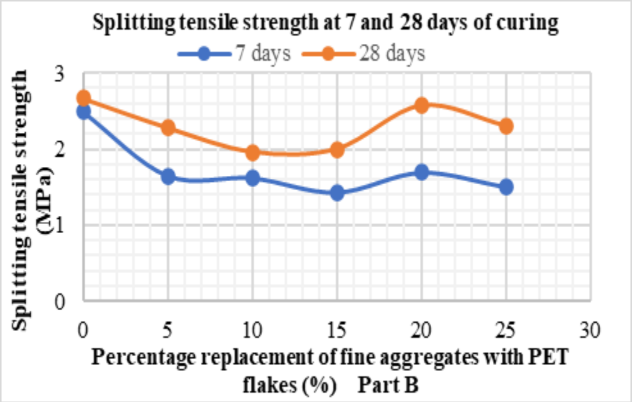
However, there are studies where the strength reduces with increasing ratio of plastic flakes [11], [12], [25], [33]. This could be due to the improper blending of plastic and/or a decrease in adhesive strength between the surface of the plastic and the cement paste. In Figure 8C, the batch mix with 5% SCBA and 5% plastic flakes gives higher compressive strength than that of the control mix. However, for other mix batches of various percentages of SCBA and plastic flakes as partial replacements compressive strength is less than that for the control mix both at 7 and 28 days. Mix batch 3(5% SCBA + 10% PET) and 5(10% SCBA and 5% PET) obtained the target strength of concrete. So, these mix proportions can equally be used in the mix design of concrete

e. Split Tensile Strength

The trend of tensile strength development among all mixes follows an almost similar trend to that of compressive strength at all ages. The split tensile strength of the specimen with 10% and 15% replacement of cement with SCBA increased at a percentage of 21.35% and 13.11% compared to that of the control mix. The split tensile strength started reducing at a percentage of 6.74% for 20% replacement of SCBA compared to that of the conventional concrete at 28 days as shown in Figure 12. The reductions in the Splitting Tensile Strength could be related to the reduction in compressive strength and the SCBA could reduce the bonding properties of the constituent materials in the concrete as compared to the cement. Similar studies were carried out and observed similar findings [2] and [30].





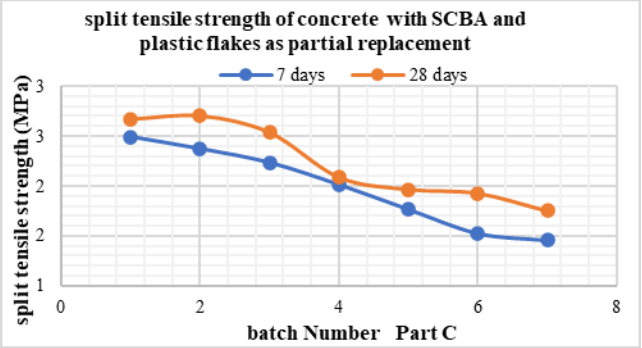


Figure 9: Effect of Part A, SCBA Replacement of Cement; Part B, Plastic Flakes Replacement of Fine Aggregates; Part C, SCBA and Plastic Flakes Replacement of Cement and Fine Aggregates on the Tensile Strength of Concrete

There was a decrease in the split tensile strength of the concrete as compared to the control mix at all the PET percentage blends, unlike the compressive strength which increase with the increase of plastic ratio. The percentage reductions of 1.12%, 4.12%, 8.99%, 10.11%, and 13.48% were recorded for 5%, 10%, 15%, 20%, and 25% replacement of fine aggregates with PET flakes with comparison to that of the conventional concrete at 28 days as shown in figure 13. The reduction of the split tensile strength with an increasing percentage of PET flakes replacing fine aggregates could have been due to the dimensions and the shape of the plastics. This reduction could have also been due to the difference in stiffness and shape of the fine aggregates. Similar findings were reported by [12], [25] and [11]. Figure 14 shows the behavior of concrete exposed to split tensile stress for the various batches with varying amounts in SCBA and plastic flakes. It was observed that only batch 2 (5% SCBA and 5% PET) had a higher split tensile strength of 1.24% than that of the control mix. All other mixed batches had lower tensile strength than the control mix. This behavior is similar to that of the compressive strength. This can be due to the poor bonding of the plastic flakes and fine aggregates with the binding materials. Additionally, as the quantity of SCBA increases, more hydrating water would be required to ensure an effective reaction of the silica it contains with the CaO in cement.

f. Flexural Strength

The flexural results shown in Figure 10 followed a similar trend as that of the compressive strength. The mix in Figure 10A with 10% SCBA had the highest flexural strength, which was 5.28 % greater than the control mix. Mixes with 15% and 20% had 6.28% and 12.311% respectively lower strength than the control mix. A similar observation was made in [4]. Figure 10B, shows the results of flexural strength of plastic flakes. The flexural strength increased with increasing percentage of plastic flakes in concrete. The strength increased by 0.25%, 1.26%, 5.28%, 6.78%, and 8.79% for 5%, 10%, 15%, 20% and 25% replacement respectively.

In reference [4], the study portrayed a similar observation where the percentage increase of plastic granules increased the flexural strength of concrete. For mixes with both SCBA and plastic flakes, figure 10C, batch 2 (5% SCBA and 5% PET) had higher flexural strength than the control mix. The other batches 3, 4, 5, 6, and 7 had lower compressive strength than the control mix. This could have been due to the low bond strength between the cement and sugarcane bagasse matrix.

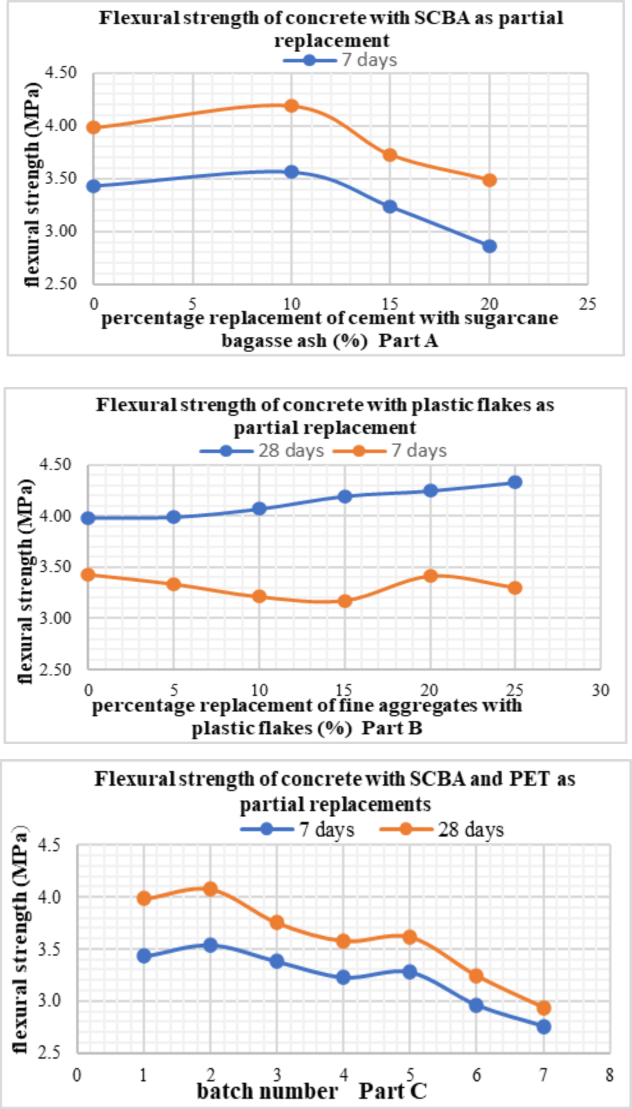


Figure 10: Effect of Part A, SCBA Replacement of Cement; Part B, Plastic Flakes Replacement of Fine Aggregates; Part C, Scba and Plastic Flakes Replacement of Cement and Fine Aggregates on the Flexural Strength of Concrete

g. Water Absorption

In figure 11 A and B, the percentage of water absorption increases with an increase in the percentage of replacements. In Figure 18, The percentage increase in the water absorption is 44.64%, 36.42%, and 32.58% at 10%, 15%, and 20% SCBA substitution for cement respectively. The reason for this increase in water absorption could be a result of the SCBA being finer than OPC and the poor compaction of the mix implying that it would therefore absorb more water as compared to the concrete with only OPC. This increase in water absorption with SCBA is in agreement with reference [7] research findings.

Plastic flake incorporation in the concrete mix increased the water absorption of the mixes. Mixes of 5%, 10%, 15%, 20%, and 25% had a percentage increase in the water absorption of 8.04%, 21.43%, 25.89%, 35.71%, and 43.75% respectively as compared to the control mix. The increment in water absorption could be a result of the poor compaction leading to poor bonding which could increase the number of pores in the concrete specimen causing it to absorb more water. For mixes with SCBA and plastic flakes, figure 11C, water absorption for batches 2, 3, and 5 have lower water absorption percentages compared to the control mix. Batch 4,6 and 7 had a slightly higher water absorption rate compared to the control mix.

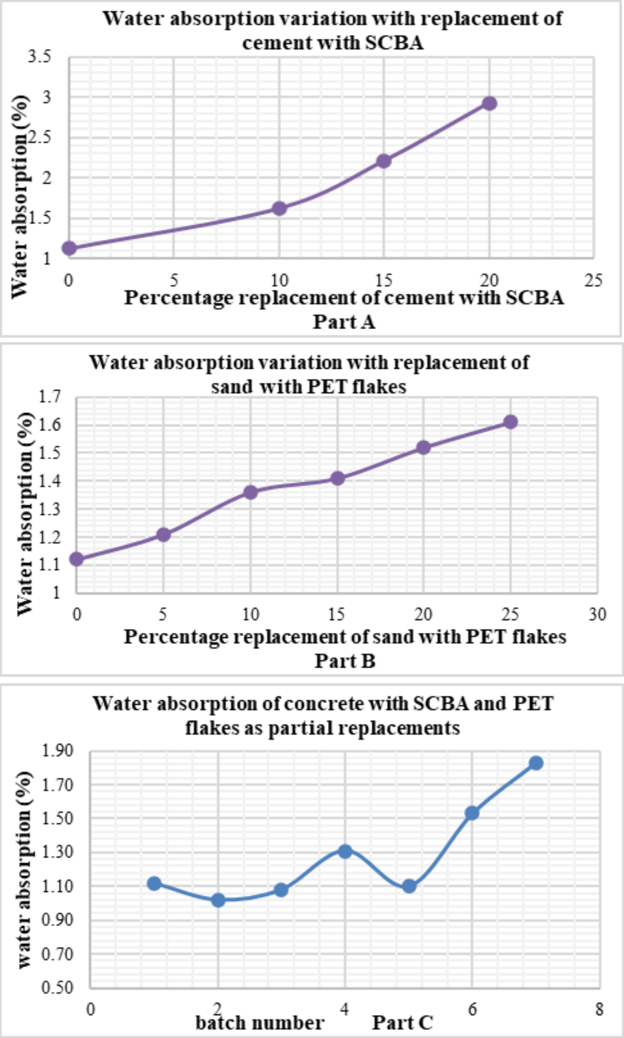


Figure 11: Effect of Part A, SCBA Replacement of Cement; Part B, Plastic Flakes Replacement of Fine Aggregates; Part C, SCBA and Plastic Flakes Replacement of Cement and Fine Aggregates on the Water Absorption of Concrete

A. Experimental Structural Analysis of Reinforced Slab

The structural behavior of a material is determined by several factors like the ultimate load, deflection of the specimen, cracking patterns, and the stress-strain relationships that occur.

a) Ultimate Load-Deflection Behavior

The ultimate load exerted on the specimens is determined by using a load cell connected to a data logger. The LVDT is placed at the bottom center of the specimens to measure deflection. During the initial stages, the specimens exhibit linear behavior in the ultimate load-deflection curves (as shown in Figure 12). However, at the first crack, the slope changes. After the first crack, the deflection of the SCBA-plastic flake slab increases less progressively than that of the control slab with increasing load. This suggests that the SCBA-plastic slab has better flexural rigidity compared to the control slab. Therefore, this design method is recommended for structural members designed to withstand flexural performance.

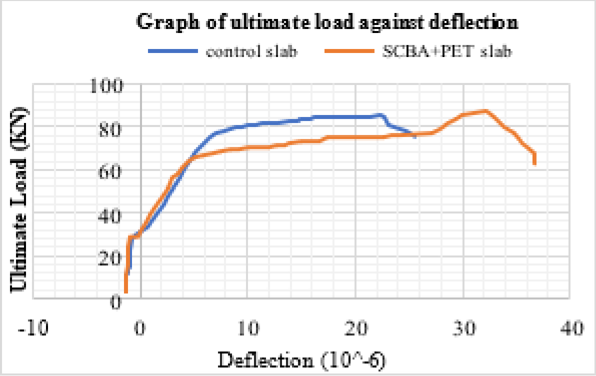


Figure 12: Ultimate Load-Deflection Behavior of the Control Slab and SCBA-Plastic Flake Slab

b) Crack patterns

To assess the behavior of the crack patterns of the specimens, crack formation is monitored during the testing process. The first cracks are obtained at 35.6988KN and 55.2325KN ultimate load for the control slab and SCBA-plastic flake slab respectively. In general, the specimens show flexural failure mode. The SCBA-plastic flake slab shows less crack width compared to the control slab for a similar ultimate load as shown in Figure 13.

Part A **Part B**

Figure 13: Crack Patterns for Scba-Plastic Flake Slab, Part A, and for Control Slab, Part B

V. CONCLUSION

Researchers aim to explore the feasibility of using sustainable and eco-friendly materials for the production of reinforced concrete slabs in this study. The study involves using 5% SCBA and 5% plastic flakes to partially replace cement and fine aggregates, respectively. The impact of this substitution on various aspects such as workability, compressive strength, split tensile strength, flexural strength, water absorption, and structural behavior of the SCBA-plastic flake slab is more effective compared to the control specimens. The results demonstrate that the workability of concrete decreases with an increase in SCBA and plastic flake content. At 28 days of age, compressive strength, split tensile strength, and flexural strength follow a similar trend. The addition of 5% SCBA and 5% PET flakes, 5% SCBA and 10% PET flakes, and 10% SCBA and 5% PET flakes has a low rate of water absorption. This gives the potential to enhance the durability of concrete. Therefore, by using SCBA as a replacement for cement and plastic flakes as a partial replacement of fine aggregates in a reasonable portion, these materials can improve the structural performance of reinforced concrete slabs and consequently other concrete structural members.

RECOMMENDATIONS

The researchers suggest conducting a numerical analysis of concrete structural members that use sugarcane bagasse ash and plastic flakes as partial replacements. It is also recommended to carry out finite element analysis to evaluate the bonding behavior of the constituent materials used in the concrete with sugarcane bagasse ash and plastic flakes as partial replacements. Furthermore, further studies should be conducted on the mechanical properties of concrete with sugarcane bagasse ash and plastic flakes as partial replacements at curing ages exceeding 28 days, as the development of concrete strength is slightly slower in the early stages of curing. Additionally, it is necessary to carry out finite element analysis to assess the bonding behavior of the constituent materials used in concrete with sugarcane bagasse ash and plastic flakes as partial replacements.

DECLARATION STATEMENT

Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	**Charity Aliyinza**: Conceptualisation, Methodology, Investigation, Formal analysis, Data curation, Writing – Original Draft – Review & Editing, Visualisation. **Christopher Kanali**: Conceptualization, Methodology, Writing –Original Draft –Review & Editing, Supervision. **Ronoh Eric**: Conceptualization, Methodology, Writing –Original Draft –Review & Editing, Supervision.

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