A Review of Bending Behaviour and Allied Properties of Reinforced Concrete Beams Containing Agro-waste Pozzolanic Materials as Partial Cement Replacements

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ORIGINAL RESEARCH

Abstract— Widespread usage of agro-based pozzolanic materials as partial cement replacement in structural concrete production will address sustainability issues. It will also address environmental concerns associated with using non-renewable resources to produce cement. However, its usage in reinforced concrete will only be possible with an understanding of agro-waste-ash-reinforced concrete analysis and design. This review examines extant literature on bending behaviour and other associated issues like crack propagation, development, and dimensions in concrete containing agro-based wastes as a partial cement replacement. While the results show an encouraging bending performance of concrete containing agro-based wastes as a partial replacement for cement (incorporating agro-based ash in reinforced concrete up to 10.0% by weight of cement resulted in improved beam bending strength and crack resistance), this optimum replacement ratio (10%) is crucial to maximising environmental benefits and mechanical performance, excessively high replacement levels, above the optimum, can negatively impact strength. There needs to be a record of the analysis and design of reinforced concrete beams produced with agro-waste ash as a partial replacement for cement. More information is needed on the provisions and recommendations in the various existing national standards for the reinforced concrete design of beams with agro-based pozzolans as a partial cement replacement. Thus, future research should analyse and design agro-waste-ash-reinforced concrete using existing design codes and technical guidance; doing this will help promote the use of agro-based waste in reinforced concrete production for its sustainability.

Keywords— Agro-waste pozzolanic materials, Allied Properties, Bending behaviour, Partial cement replacement, Reinforced concrete beams, Structural concrete.

1 Introduction

The need for concrete continues to rise due to the numerous building operations required to support the present civilisation and meet the housing demands of low-income earners, who constitute the bulk of the population in Nigeria (Ikponmwosa et al., 2015), and to provide structures of various forms, ranging from religious to institutional buildings (Osanyinlokun et al., 2024). The demand for concrete arose because it is durable and can withstand various weather conditions. None of the construction materials used in a built environment has matched concrete in terms of acceptability on all lands. Its acceptability was based on many factors, which include the availability of materials for its production at every place, the ability to be produced to have any desired specified strength, the fact that it enables builders and engineers to play with any geometric shapes, and excellent durability properties, among others (Fapohunda et al., 2023).

However, its usage resulted in the mass extraction of non-renewable natural resources, such as sand, granite, and limestone, among others, necessary for concrete manufacturing (Fapohunda et al., 2016). As a result, it has had a severe environmental impact due to resource depletion, high greenhouse gas (GHG) emissions, and high energy usage (Osanyinlokun et al., 2024). Even though concrete is made of cement, sand, gravel, and water, cement is the costliest component (Ikponmwosa et al., 2015). Cement manufacture, a key component of concrete mixtures, contributes to roughly 5% - 8% of worldwide CO2 emissions (Saha, 2018; Alex et al., 2016; and Siddika et al., 2020). While considerable success has been recorded in sourcing suitable concrete materials from industrial wastes like silica fume, fly ash, and slag (SFA, 2005; Thomas, 2007; and Fapohunda, 2010), the current focus of researchers aims to examine the possibility of partially using alternate materials in the ash form to substitute cement from agricultural waste. The materials found are corn cob ash (Olafusi et al., 2016), eggshell powder (Rahman et al., 2019), palm oil fuel ash (Rahman et al., 2019), pulverised bone (Falade et al., 2014), and rice husk ash (Chin et al., 2010; Naresh et al., 2016; Siddika et al., 2021; Singh & Singh, 2016; and Tahir et al., 2020). Others are rice straw ash (El-Sayed et al., 2019), sawdust ash (Auta et al., 2016), sugarcane bagasse ash (Ansa & Mohan, 2015; Mutua, 2017; and Joy et al., 2017), and wheat straw ash (El-Sayed et al., 2019). The literature reports these materials as pozzolanic, meaning they are aluminium-siliceous or siliceous composite parts with no or negligible cement properties. When well-powdered, these substances can react with Ca (OH) 2 in the presence of H2O at room temperature to produce chemicals collected into a mass (Malhotra & Mehta, 1996).

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Abundant literature exists on partially using agro-based ash to replace cement in concrete production; this literature investigated many properties, like compressive strength, density, consistency, durability, and microstructural investigations. Joel (2010) conducted many extensive reviews on each of the following as partial substitutes for cement: acha husk ash (AHA), Bambara groundnut husk ash (BGHA), bone powder ash (BPA), groundnut husk ash (GHA), rice husk ash (RHA), and wood ash (WA). In addition, Joel (2010) also investigated their compressive strength. Fapohunda et al. (2017) provided an in-depth and up-to-date assessment of several researchers' work on the construction and characteristics of concrete utilising rice husk ash (RHA) as a partial substitute for regular Portland cement. Fapohunda et al. (2018) also investigated the characteristics, structural behaviour, and future applications of concrete using sawdust ash (SDA) as a partial cement substitute. In another study, Kilani et al. (2021) present an overview of the effects of coconut shell ash (CSA) and sugarcane bagasse ash (SCBA) on concrete and composite mechanical properties. Similar studies were also conducted by Fapohunda et al. (2021) on cassava peel ash (CPA), empty palm oil-fruit bunch ash (EPO-FBA), rice husk ash (RHA), and sawdust ash (SDA), additional ingredients were corncob ash (CCA), eggshell powder (ESP), groundnut husk ash (GHA), and palm kernel shell ash (PKSA). However, in all these reviews, the authors gave little or no attention to such properties as bending responses and allied properties like crack development, propagation, and patterns in reinforced concrete slabs or beams with agro-based ash as partial cement replacement. This aspect of work is essential for the following reasons:

1. Materials without satisfactory bending performance cannot be used as flexural structural materials, such as slabs, walls, etc. Thus, such a review will enable concrete users to assess its suitability for structural work.
2. Such review work will reveal areas of bending that are yet to be satisfactorily covered, thus giving investigation directions to researchers.
3. Analysis of such reviews will help determine the sufficiency or otherwise of the relevant provisions in the present national codes for structural concrete design with agro-based concrete.

Thus, this work aims to extensively review and analyse past research findings on RC beams incorporating agricultural waste as a partial cement replacement. In addition, other associated issues with bending will also be reviewed, like failure modes, crack propagation, crack width, and crack pattern.

2 Methodology

This review comprehensively compiles and analyses publicly available research on the bending performance of RC beams incorporating agro-based waste materials as partial cement replacements. The included studies originate from university libraries, repositories, electronic media, and the Internet.

2.1 Inclusion Criteria

Studies investigating the bending performance of RC beams containing one, two, and three types of agro-based waste material as a partial cement replacement. Studies utilising commonly found agro-based waste materials, including corncob ash (CCA), eggshell powder (ESP), palm oil fuel ash (POFA), pulverised bone (PB), rice husk ash (RHA), rice straw ash (RSA), sawdust ash (SDA), sugarcane bagasse ash (SCBA), and wheat straw ash (WSA).

Studies published or readily accessible in the public domain (university libraries, online repositories, open access journals)–studies employing standard testing methods for evaluating the bending performance of RC beams.

2.2 Exclusion Criteria

Studies focusing on other structural elements besides RC beams (e.g., columns, slabs). Studies utilising uncommon or proprietary waste materials.

Studies published behind paywalls or inaccessible in non-public repositories. Studies employing non-standard or poorly documented testing procedures.

2.3 Search Strategy

A systematic search was conducted using relevant keywords and Boolean operators ("OR", "AND", "NOT") through online databases of academic publications, including ScienceDirect, ASCE Library, SpringerLink, Google Scholar, and Engineering Village. Additional sources were identified by manually referencing the bibliographies of existing review papers and critical research articles. The following search terms were used, combined in various combinations: “structural concrete”, “design standard”, “concrete design”, “allied properties”, "RC beams", "bending performance", "bending behaviour", "agro-waste pozzolanic materials", "reinforced concrete beams", "agro-based waste", "partial cement replacement", "corncob ash", "eggshell powder", "palm oil fuel ash", "pulverised bone", "rice husk ash", "rice straw ash", "sawdust ash", "sugarcane bagasse ash", "wheat straw ash". The search encompassed publications from the past [28 years] to capture the latest advancements in the field.

3 Literature Review

3.1 Bending Responses of Reinforced Concrete Beams (RCB) with Corn Cob Ash (CCA)

Olafusi et al. (2016) investigated the flexural ability of self-compacting concrete (SCC) with corncob ash. They published the findings of flexural tests on the loads at first crack Pcr, ultimate load at failure, Pu, and the rupture modulus (MOR). Table 1 shows 36 samples of 0.150 × 0.150 × 0.600 m RCB created from 12 numbers of self-compacting concrete mix. Water binder ratios for six mixes were between 0.38 and 0.40 (all samples), along with a 2 L/100 kg water-reducing admixture for samples A – J, excluding samples K and L. Control SCC samples A and B had zero per cent corncob ash substitution for cement.

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Table 1. Results of Flexural Examinations

Sample	Density (Kg/m³)	Pcr (KN)	Pu (KN)	Pcr/Pu	M.R. (N/mm²)	Failure Mode
A	2000.0	30.0	148.4	0.202	14.8	Shear failure
B	1976.0	33.3	132.7	0.251	13.3	Shear failure
C	2000.0	28.3	91.9	0.308	9.2	Shear failure
D	2025.0	31.7	97.0	0.327	9.7	Shear failure
E	1926.0	40.0	82.8	0.483	8.3	Shear failure
F	1926.0	47.7	83.5	0.571	8.4	Shear failure
G	1926.0	39.7	82.6	0.481	8.3	Shear failure
H	1926.0	42.3	83.3	0.508	8.3	Shear failure
I	1879.0	24.7	80.7	0.306	8.1	Shear failure
J	1901.0	29.0	82.5	0.352	8.3	Shear failure
K	1988.0	25.7	103.9	0.247	10.4	Shear failure
L	2025.0	28.0	110.0	0.255	11.0	Shear failure

Source: (Olafusi et al., 2016).

Samples C and D had five per cent corncob ash blended self-compacting concrete. In contrast, samples E and F contained ten per cent corncob ash blended self-compacting concrete, samples G and H contained fifteen per cent corncob ash blended self-compacting concrete, and samples I and J contained twenty per cent corncob ash blended self-compacting concrete. Sample K and sample L, on the other hand, contained zero per cent corncob ash blended self-compacting concrete, which was comparable to sample A and sample B; however, they were without water-reducing superplasticisers. Sample A had the maximum rupture modulus (MOR) of 14.8 N/mm2, whereas sample I had the least MOR of 8.1 N/mm2. Also, except for the control specimen, the loads at failure and MOR of the beams tested rose as the water-binder ratio became greater as CCA decreased. Figure 1 indicates that the failure patterns for all beam specimens evaluated were comparable since they all displayed a diagonal crack pattern (shear failure).

Fig. 1. Failure pattern of tested beams (Olafusi et al., 2016).

Figure 2 shows that the first fracture loads on the CCA composite beam were thirty-one to fifty-seven per cent of their ultimate loads at failure, whereas the loads at the first crack on the specimens of the beam without corncob ash were lower than twenty-six per cent.

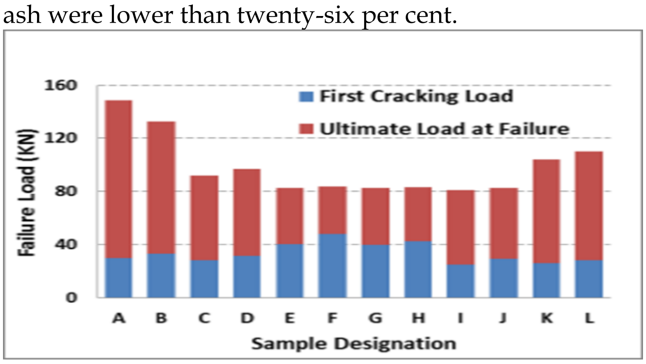

Fig. 2. Crack development in beams (Olafusi et al., 2016).

Figure 3 depicts the load-vs.-deflection (P-δ) response of the CCA-containing specimens of the beam, indicating that sample C and sample D with five per cent corncob ash substitution exhibited stiffness qualities similar to sample A, sample B, sample K and sample L (the mixes that do not contain corncob ash), compared to the other CCA-containing specimens of the beam. The control sample exhibited the highest stiffness attribute. The P-δ curves of the mixtures containing CCA over 5% replacements were comparable, and their stiffness decreased as the CCA concentration rose.

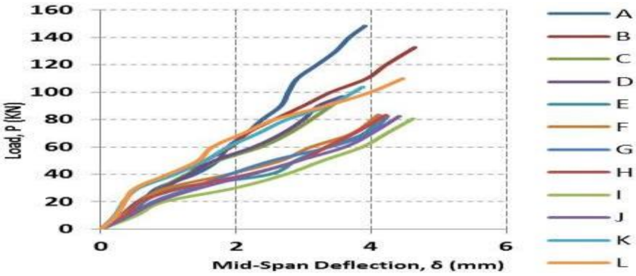

Fig. 3. Load-deflection curve (Olafusi et al., 2016).

First, the study found that the rupture modulus of self-compacting concrete beams with corncob ash content rose with increasing ratios of water-binders and decreased with increasing corncob ash concentrations. They also discovered that beams containing CCA have a lower post-first crack loading ability; beams with corncob ash had higher durability characteristics in first crack development than samples without corncob ash content. Second, when CCA concentration increases, the rigidity of CCA-containing beams decreases. In contrast, samples containing five per cent corncob ash show comparable stiffness to control samples, suggesting that 5% CCA is the essential quantity structurally advantageous.

3.2 Bending Responses of Reinforced Concrete (RC) Beams with Eggshell Powder (ESP) and Palm Oil Fuel Ash (POFA)

Rahman et al. (2019) examined the bending performance of the combined use of eggshell powder (ESP) and palm oil fuel ash (POFA) to partially replace cement.

The addition of POFA, as well as eggshell, increased the beam's flexural strength. Three significant conclusions highlighted the experimental and FEA results compared concrete mixes using 20% POFA and 5% ESP (20P5E), 20% POFA and 10% ESP (20P10E), and control. First, the ultimate load capacity of the beam, 20P05E and 20P10E, is more significant, with + thirteen per cent and + fourteen per cent values, respectively, as shown in Table 2.

Table 2. Flexural strength for the control, 20P05E and 20P10E beam

Type of Beam	Age (days)	Average flexural strength (MPa)	Percentage difference versus the control mix (%)
Control	28	7.79	
20P05E	28	9.00	+13.0
20P10E	28	9.18	+14.0

Source: (Rahman et al., 2019).

Secondly, as indicated in Table 3, the early fractures develop around 6kN, or roughly 39% of the ultimate load for each beam.

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Table 3. Beam's failure mode and cracking load

Type of Beam	1st Crack			Mode of Failure	
Concrete Mix	Crack Load (kN)	Percentage of ultimate load (%)	Size (mm)	Type of failure	Ultimate load (kN)
Control	6.00	39	50	Flexure-Shear	16
20P05E	7.19	40	93	Flexure	18
20P10E	7.21	39	80	Flexure-Shear	18

Source: (Rahman et al., 2019).

Third, the documented cracking pattern has spread inside the zone of flexure. The control sample and 20P10E strain pattern show linear increases inside the elasticity zone until seventy per cent % of corresponding ultimate loads are reached. As seen in Figure 4(a-c), the 20P05E mix is non-linear at the first 2.00 strain increase in all the zones.

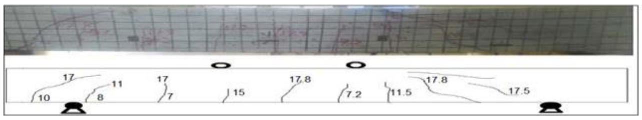

Fig. 4(a). The control beam specimen cracking pattern (Rahman et al., 2019).

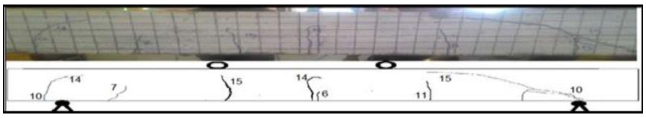

Fig. 4(b). The 20P05E beam specimen cracking pattern (Rahman et al., 2019).

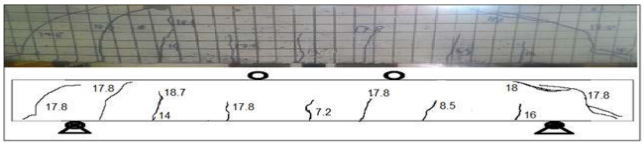

Fig. 4(c). The 20P10E beam specimen cracking pattern (Rahman et al., 2019).

Figure 5 shows a comparison of beam defection vs. axial load. Again, the displacement happened at both sites of loading of the beam and shared a similar profile of displacement, demonstrating that the loadings of the beam were balanced. When the load is applied at fifty per cent of the value of the ultimate load, a likeness displacement pattern of up to 2 mm is seen. The mix 20P10E showed displacement when exerted 6 kN; the load gradually increased towards a maximum value of 7.25mm at 18.2 kN. Mix 20P5E, on the other hand, has an optimum deflection of 5.81 mm at 18.0 kN, while the control beam has an average displacement of 4.59mm at 15.6 kN. Compared to the control mix, both FC-POFA-ES mixes had lower displacement values when attaining 15.6 kN at 2.13 mm and 2.85 mm, respectively, demonstrating superior displacement performance.

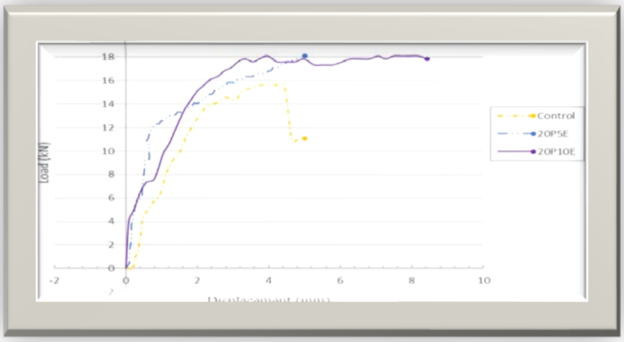

Fig. 5. FC-POFA-ES beam's Ultimate load versus vertical displacement (Rahman et al., 2019).

The displacement values of FC-POFA-ES are shown in Table 4. Mix type 20P5E has the highest bending resistance ratio at the maximal load. Therefore, on average, both mixes have larger displacement values than the control mix. Figures 6(a) - 6(b) show the horizontal strain distribution of the beam at mid-span.

Table 4. Vertical load versus average displacement of beam specimens

Type of Beam	Ultimate load	Average displacement (mm)	Difference of displacement versus control mix (%)
Control	15.58	4.59	
20P5E	18.00	5.78	+20
20P10E	18.19	7.31	+36

Source: (Rahman et al., 2019).

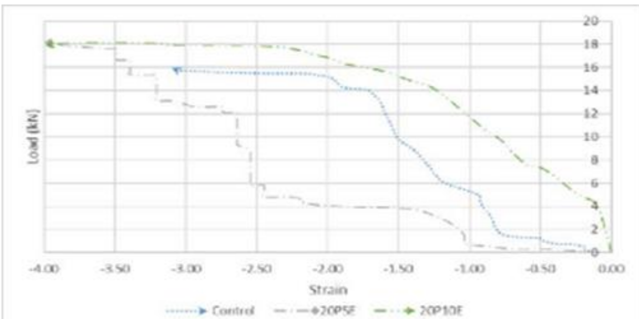

Fig. 6(a). Load vs. mid-span axial strain - Tension zone (Rahman et al., 2019).

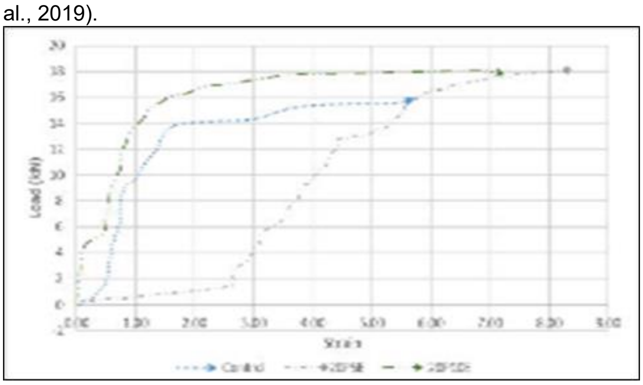

Fig. 6(b). Load vs. mid-span axial strain - Compression zone (Rahman et al., 2019).

For strain patterns, the 20P10E and control mix exhibit a linear increase inside the elasticity zone until seventy per cent of their ultimate load. Meanwhile, the 20P5E mix is non-linear in both zones at the first 2.00 strain increment. These patterns were generated by a combination of

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inconsistencies throughout the loading increase and imperfections on the surface of the beam, resulting in hair cracking. In addition, both 20P05E and 20P10E mixes had a more significant maximum strain in the compression and tension zones than the control beam. Mix 20P10E, for example, has a strain value of 7.27 and -3.91 at an ultimate load of 18.1kN, whereas mix 20P5E has a strain value of 8.30 and -4.11 with an ultimate load of 18.0. As a result, adding 10% Eggshell Powder (ESP) and 20% Palm Oil Fuel Ash (POFA) resulted in more excellent strain resistance against the applied load, which can help the beam withstand loading.

3.3 Bending Performance of Reinforced Concrete Beams with Pulverised Bone (PB)

Falade et al. (2014) examined the bending response of foam concrete incorporating pulverised bone as a partial substitute for cement. Crack pattern and development, mode of failure, experimental and theoretical ultimate moments, ultimate load, deflection and stiffness are the bending parameters addressed in their study. Their investigation showed the following findings: First, an increase in the pulverised bone does not affect the crack formation and propagation or failure mode; the beam specimens' deflection increases as the amount of pulverised bone content in the mix increases; an increase in pulverised bone content results in a reduction in the bending moment. Second, adding pulverised bone up to a fifteen per cent substitute level does not affect the rigidity of foam concrete.
Using reinforcement significantly improves the flexural performance of foam concrete.

3.4 Bending Performance of Reinforced Concrete Beams with Rice Husk Ash (RHA)

Several authors have reported varied results depending on the flexural performance of reinforced concrete with a rice-husk mix ratio. For example, Singh and Singh (2016) studied the strength characteristics of concrete. They observed that the flexural strength is optimal for various percentages of RHA compared to the control mix, i.e., it is raised by 10.9% for the mix containing 5% rice husk ash (M-RHA5). However, the mix containing 10% rice husk ash (M-RHA10) decreases by 3% compared to the control mix, as illustrated in Figure 7.

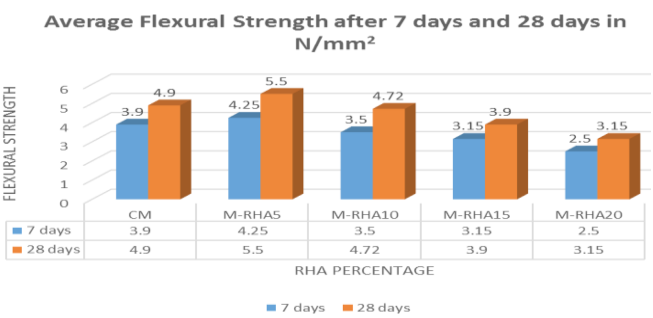

Fig. 7. Flexural Strength after 7 and 28 Days in N/mm^2 (Singh & Singh, 2016).

Tensile stresses emerge when RHA-reinforced concrete and composite beams are loaded in pure bending, as seen in Figure 7. Because of the fracture-arresting effect of the closely spaced fibres, the load at the initial crack would rise in rice husk ash-reinforced concrete. After the concrete matrix fractures, the fibres continue to bear a more significant load, which is given. As a result, flexure strength improves by 12% in M-RHA5 and then declines. M-RHA10 reduces by 3.6% owing to the influence on the heat of hydration, while M-RHA15 and M-RHA20 decrease by 20.4% and 35.7%, respectively. As a result, the ideal content for Rice Husk Ash (RHA) in cement is 5% since strength is improved compared to the control mix. Similarly, Naresh et al. (2016) experimentally evaluated concrete flexural strength. Their results revealed that the flexural strength values were marginally lower than the control mix concrete at all the ages of curing investigated, as shown in Table 5 and Figure 8.

Table 5. Flexural Strength of Beams replaced with RHA at 28, 56, and 90 days

Sample Designation	% Of RHA	Flexural Strength of Beam Specimens in N/mm^2		
		28 days	56 days	90 days
M-0	*0*	*13.20*	*15.90*	*17.89*
M-5	*5*	*12.89*	*14.60*	*17.08*
M-10	*10*	*12.11*	*13.81*	*15.11*
M-15	*15*	*10.69*	*12.11*	*13.71*
M-20	*20*	*9.11*	*10.59*	*12.28*
M-25	*25*	*7.66*	*8.51*	*10.09*

Source: (Singh & Singh, 2016).

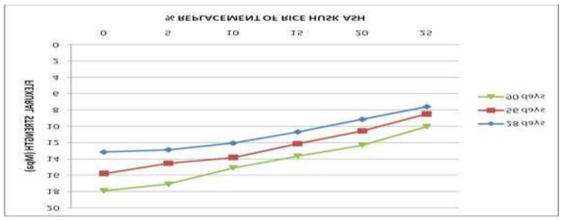

Fig. 8. Variations in the bending strengths substituted with rice husk ash at 28 days, 56 days, and 90 days (Singh & Singh, 2016).

Similar work done by Siddika et al. (2021) was on the performance of RCB. The findings of the experimental tests reveal that the investigated by-products or waste materials may replace roughly 20% of common ingredients in concrete without considerably impairing the strength qualities. However, too much might be harmful. The bending strength of these RCB casts with various combinations is shown in Figure 9. The additions of Fly Ash (FA) and Stone Dust (SD) significantly increase these specimens' flexural strength, whereas the addition of Rice Husk Ash (RHA) decreases the control specimen's strength. The F5R5S10 and F10R5S0 samples outperform the control specimens by 20% and 26%, respectively. However, flexural strength is reduced when more than 5% RHA is added. The collapse of all RC beams was caused by concrete crushing triggered by shear fractures (Figure 10). The control sample made of regular cement and sand fails in bending, causing bending fractures in the middle span at the maximal flexure zone. The justification for this is that the concrete's shear strength in these sustainable concrete examples is low, resulting in material failure before significant yielding of the steel rebars. The analysis of the mode of failure and the strength diagram reveals that employing the SD enhances the concrete's compression and tension capability due to

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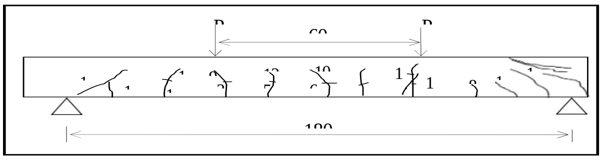
its stress-transferring and filler properties. However, employing too much RHA has the reverse effect. When the optimal number of additional materials is exceeded,



all supplementary materials have a detrimental impact on the characteristics of concrete. The test demonstrates that sustainable concrete mixes are appropriate for an under-reinforced structural system to build low-cost and lightweight structural systems.

Based on the experimental test findings, we can infer that the best combination identified in the research is five per cent weight of Fly Ash, five per cent weight of Rice Husk Ash as cement substitutes and 10% weight of Stone Dust as a substitute for nature's sands without reducing the strength of the concrete.

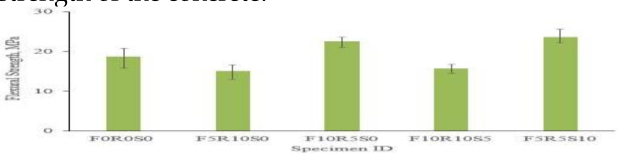


Fig. 9. Bending strength of reinforced concrete beam containing separate concrete mixes (Siddika *et al.*, 2021).

Fig. 10(a). Failure mode for reinforced concrete beam sample cast with F0R0S0 (Siddika et al., 2021).

Fig. 10(b). Failure mode for reinforced concrete beam sample cast with F5R10S0 (Siddika *et al.*, 2021).

Fig. 10(c). Failure mode for reinforced concrete beam sample cast with F10R5S0 (Siddika *et al.*, 2021).

Fig. 10(d). Failure mode for reinforced concrete beam sample cast with F10R10S5 (Siddika *et al.*, 2021).

Fig. 10(e). Failure mode for reinforced concrete beam sample cast with F5R5S10 (Siddika *et al.*, 2021).

Chin et al. (2010) examined the load versus deflection response and fracture modes of RCB exposed to 4-point loading. The results demonstrated that RHA-reinforced concrete beams using used motor oil and superplasticiser have 18-26% greater capacity than their matching control mix. The crack patterns for the 20% rice husk ash mixed cement-concrete beams were documented. The findings were comparable to the two other beam groups. When the pressure was raised, fracture trends emerged over the beam's constant moment area length. Tensile fracture patterns were visible near the support in the beams. These fractures then spread in the diagonal direction towards the area of load P, eventually transforming into diagonal shear cracks before failing. The failure was brittle and sudden. All of the beams had the same cracking and failure patterns. The fracture patterns of rice husk ash-concrete beams are seen in Figure 11-12.

Fig. 11. The crack patterns of reinforced concrete beam twenty per cent RHA contain 0.15 per cent used engine oil, 20%RHA/UEO (Chin et al., 2010).

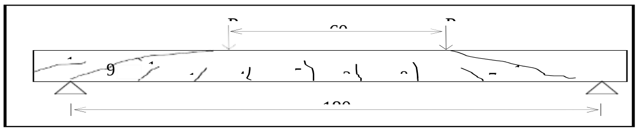


Fig. 12. The Crack patterns of reinforced concrete beams twenty per cent RHA contain 0.15 per cent superplasticiser, 20%RHA/SP (Chin et al., 2010).

Figure 13 depicts the load versus deflection graphs of twenty per cent rice husk ash-concrete beams comprising 20%RHA/UEO, 20%RHA/SP, and 20%RHA.

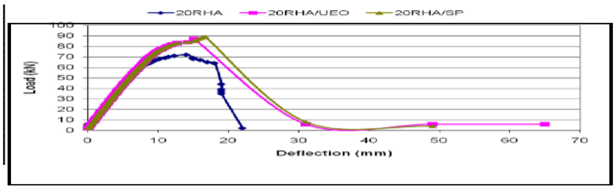


Fig. 13. Load versus deflection curves of twenty per cent RHA-concrete beams (Chin et al., 2010).

The concrete beams produced by the mixes 20%RHA/UEO and 20%RHA/SP had twenty-one per cent and twenty-four per cent greater ultimate load capacity than the twenty per cent rice husk ash' beam, with 72.1 kN. Consequently, the maximum deflection of 20RHA, 20RHA/UEO and 20RHA/SP beams was 14.20mm, 15.10mm, and 16.70mm, respectively. Tahir et al. (2020) investigated the structural behaviour of Reinforced Aerated Concrete Beams (RAC-B) exposed to flexural load using experimental and computational methods. The parametric study results showed that Reinforced Aerated Concrete Beam mixes containing 10% Rice Husk Ash (RAC-10%RHA-B) with greater depth structurally performed better under flexure with greater load-carrying capacity, fewer maximum deflection and fewer cracks developing in the tension area than Reinforced Aerated Concrete Beams mixes containing 0% Rice Husk Ash (RAC-B) (Control Sample).

3.5 Bending Performance Of Reinforced Concrete Beams With Rice Husk Ash, Rice Straw Ash, And Wheat Straw Ash

El-Sayed et al. (2019) reported on the bending response of RCB using RHA, RSA, and WSA under static loading circumstances while employing mixed agricultural waste as a cement reinforcing material. The study found that it has a higher load-carrying ability for various combinations, indicating that it might be employed as a cement-reinforcing material. Furthermore, the findings of

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the experiments demonstrated that a 15% optimum ratio of WSA and RSA enhanced flexural behaviour. The sample of its crack propagation and the failure mode is shown in Figure 14.

Fig. 14. Sample of cracks propagation and failure mode (El-Sayed et al., 2019).

3.6 Bending Performance Of Reinforced Concrete Beams With Rice Husk Ash And Sugarcane Bagasse Ash

Ansa and Mohan (2015) investigated the bending response of ternary blended steel-fibre RCB employing SCBA and RHA as cement reinforcing materials. Figure 15 depicts a typical flexural beam crack pattern.

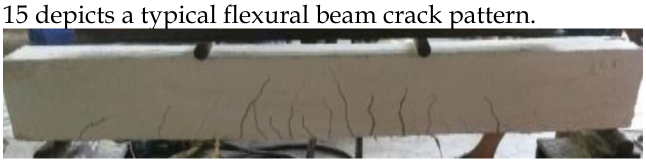

Fig. 15. Typical crack pattern of flexural beam specimen (Ansa & Mohan, 2015)

The following are the main findings of this work: First, ternary mixed concrete with twenty per cent BA and ten per cent RHA demonstrated appropriate bending strength compared to the control mix, so it was chosen as the optimal combination. Second, the load-deflection properties of the Ternary Blended steel-fibre reinforced concrete beam specimens outperformed the control mix. Third, compared with the control beam, the ternary blended steel-fibre reinforced concrete beam substantially reduces fracture width at all load levels.

3.7 Bending Responses Of RCB Containing Sawdust Ash (SDA)

Auta et al. (2016) studied the flexural strength of a reinforced vibrated concrete beam containing SDA as a partial substitute for cement. Their findings were as follows: First, the bending strength of concrete containing 5% SDA substitution of cement is somewhat less than that with 0% SDA (control) for revibrated beams but still more significant than that of the control specimen (0% SDA) non-revibrated concrete beam. Second, at all SDA % levels, the flexural strength of non-revibrated SDA concrete is dramatically reduced. The researchers concluded that adding up to 5% Sawdust Ash (SDA) to concrete, followed by re-vibration for up to 20 minutes, would raise the bending strength of RC beams.

3.8 Bending Response Of RCB Containing Sugarcane Bagasse Ash (SCBA)

Mutua (2017) evaluated the structural response of glass concrete utilising SCBA. They demonstrated that these displacements were below the permitted allowance of 20 mm set by BS 8110-1: (1997) for substituting sand with crushed glass up to thirty per cent and cement containing sugarcane bagasse ash up to fifteen per cent. The overall behaviour of the beams was that the greater the quantities of SCBA in the mix at thirty per cent glass composition, the fewer strains were induced in the beam generated; moreover, the strains rose at early loads and stayed consistent during the loading duration. The average deflection of the three beams for all concrete types under consideration was used to estimate the load versus deflection behaviour of glass-concrete beams manufactured with SCBA as cement. Figure 16 depicts the plotted findings.

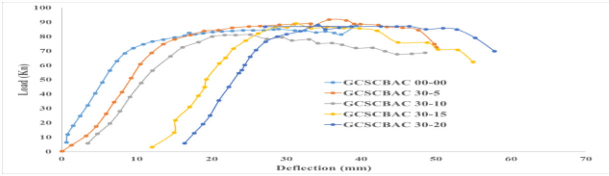

Fig. 16. Load versus deflection graphs of glass-concrete beams containing SCBA-cement (Mutua, 2017).

Figure 16 shows that all the beams for the different mix types had identical load versus deflection characteristics. They did, however, reach their final stiffness at distinct stages, with a dramatic drop in initial stiffness upon the development of substantial cracks (diagonal cracks). The control beam had the lowest ultimate load compared to beams with thirty per cent waste glass in the fine aggregates and SCBA in the cement. Deflections often increased when fine aggregates with glass were thirty per cent, and cement replacement levels with SCBA increased. Because the jerk from the load cell may have been securely positioned, the deflections did not commence at zero for all of the mixtures, requiring some load to be applied during the set-up stage before load application. In accordance with BS 6399-1 (1996), the author determined the load at service by dividing the ultimate load by 1.5. The full service and ultimate loads were taken on by GCSCBAC 30-10. Deflections at ultimate and service loads were the least for the control beam and increased as the substitute percentages rose. Only GCSCBAC 30-10, GCSCBAC 00-00, and GCSCBAC 30-5 met the deflection allowances of less than 20 mm for BS 8110-1 (1997) and deflections at service loads; all beams with mix proportions at service loads plus GCSCBAC 30-15 met the deflection allowances of less than 20 mm for BS 8110-1 (1997) of rectangular beams. As the replacement percentages increased, the deflections of all the mix proportions increased. According to the research, the flexural test revealed that the strengths of the different mixtures were lesser than those of the control mix. However, a considerable increase of up to ten per cent of cement with SCBA and a thirty per cent substitute of fine aggregates with broken glass was seen, obtaining a seventy per cent 28-day strength at seven days. Joy et al. (2017) investigate concrete strength parameters using ternary blends. Their findings revealed that the mix, including 20% Sugarcane Bagasse Ash and 10% Glass Powder, enhanced strength by 5.75% compared to the conventional mix and that the load at the first fracture was 3% greater than the conventional mix. However, they discovered that standard methods boosted flexural strength without using chemicals or superplasticisers. The experimental investigation discovered that the best mix ratio was the twenty per cent sugarcane bagasse ash

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and ten per cent glass powder combination.

4 Implications Of Agro-Based Ash For Sustainable Structural Concrete

In this review, an attempt was made to review agro-based ash's bending characteristics in concrete production. This review is part of the significant work required to capture the fundamental structural characteristics of agro-based ash use as a partial substitute for cement in concrete. Sustainability in producing structural concrete has recently become a primary global concern. There is no doubt that this review shows the potential of pozzolans from agricultural waste to enhance sustainability issues, like reducing the concrete industry's contribution to global greenhouse gas emissions and reducing the usage of non-renewable raw resources in cement production. As a result, the nation's natural resources are being conserved while unwanted garbage is removed, resulting in a cleaner environment.

5 Conclusions And Recommendations

Findings from the effect of agro-based ashes (corncob ash (CCA), eggshell powder (ESP), palm oil fuel ash (POFA), pulverised bone (PB), rice husk ash (RHA), rice straw ash (RSA), sawdust ash (SDA), sugarcane bagasse ash (SCBA), and wheat straw ash (WSA)) on the bending performance of the reinforced concrete samples revealed a nuanced relationship between agro-based ash content and bending performance. While slight reductions in bending strength were observed for higher replacement ratios (>10.0%), incorporating lower percentages (≤10.0%) displayed slightly improved bending behaviour, with a 10% replacement of agro-based ash as the optimum replacement level for concrete cube and reinforced concrete beam production because the strength of concrete gradually reduces beyond this replacement level. However, exceeding the optimum (10% Agro-based Ash) replacement level had detrimental effects on bending performance, highlighting the importance of staying within this optimum replacement level. Agro-based-Ash-RC beams at up to 10% replacement exhibited sufficient strength to meet the strength class (25 N/mm^2) standard designed for the mix, which is adequate for normal-weight concrete, while >10% Agro-based Ash can be utilised as lightweight concrete as it met the strength class (17 N/mm^2) (ASTM C 330, 2007).

The study also revealed that agro-based ash at ≤10% replacement level reduced the cracking of the concrete beams. It was observed that there was a considerable increase in the cracking load of the test specimens, with the inclusion of agro-based ash at up to 10% replacement. This means agro-based ash replacement of up to 10% makes the reinforced concrete beam denser and stiffer.

There needs to be a record of the analysis and design of reinforced concrete beams produced with agro-waste ash as a partial replacement for cement. Thus, future research should analyse and design agro-waste-ash-reinforced concrete using existing design codes and technical guidance.

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