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Enhancing Concrete Properties with Corncob Ash in Interlocking Wall Blocks

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Abstract This investigation examines the viability of corncob ash (CCA) as a sustainable substitute for cement in the formulation of interlocking concrete blocks (ICB) utilized in wingwall structures of bridges. The impetus for this study arises from the necessity to diminish the environmental footprint of construction materials and enhance the sustainability of infrastructure developments. By substituting varying proportions of cement (0%, 1%, 2%, 3%, and 4%) with CCA, this research seeks to evaluate the impact on the compressive strength, split tensile strength, and shear strength of the interlocking blocks. Comprehensive laboratory experiments were conducted to assess the mechanical properties of the CCA-modified concrete blocks. The findings revealed that a 2% substitution of cement with CCA produced the most advantageous results in compressive and tensile strength, indicating an optimal equilibrium between strength and material efficiency. Furthermore, the shear strength of the mortarless interlocking concrete blocks exhibited significant enhancement, suggesting improved structural performance. The results underscore the potential of CCA to effectively replace a portion of cement in concrete production, thereby fostering more sustainable and environmentally responsible construction methodologies without compromising structural integrity. This research advocates for the wider implementation of alternative materials in civil engineering, particularly in the context of critical infrastructure construction.

Keywords Interlocking Concrete, Corncob Ash, Sustainable Construction, Compressive Strength, Tensile Strength, Shear Strength

1. Introduction

Bridges are crucial infrastructure in transportation and trade, but they can deteriorate, leading to high repair costs and potential collapse [1, 2]. This study focuses on concrete interlock enhanced with corncob ash [3] for reinforcing bridge wingwalls [4]. The architecture, engineering, and construction (AEC) sector, responsible for around 40% of global energy [5] use and greenhouse gas emissions, faces environmental challenges, especially with rapid urbanization [6]. Interlocking Concrete Blocks (ICB), a cost-effective, eco-friendly [7, 8] alternative [9-11], produce fewer carbon emissions than traditional blocks [12, 13]. Accurate material property determination is essential in development [14].

High cement prices threaten housing accessibility, prompting researchers to seek alternative materials, including agricultural waste like corncobs [15-17]. Corncob ash, containing 65.43% silicon dioxide, aluminum oxide, and ferric oxide [7], is classified as class C pozzolan per SNI 2460. It also meets AASHTO C618 standards as a class F pozzolan [16]. This research explores sustainable materials for bridge structures [18], focusing on corncob ash in concrete interlock to reduce costs [19, 20], enhance performance, and minimize environmental impact.

Previous research has examined the structural characteristics and behaviors of different types of interlocking bricks as an alternative to conventional bricks, including developments that utilize marble powder waste and corn cob ash (CCA). For example, developed interlock bricks use marble powder (see Fig. 1), which shows high efficiency for economical and sustainable wall applications [21]. It was also reported that interlock bricks meet the minimum standards for load-bearing and non-load-bearing walls [22]. CCA at 10% provides optimal compressive strength while reducing cement consumption [4, 20], while other research reported that CCA substitution at 25%-5% results in higher compressive strength than normal concrete (see Fig. 2) [23].

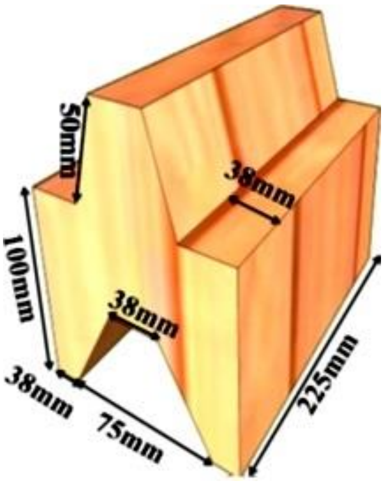

Figure 1. Interlocking block design [21]

Fig. 1 shows that the walls using these bricks show improved load capacity, crack resistance, and better shear strength compared to conventional bricks.

Fig. 2 describes that a CCA substitution of 2.5%-5% provides a greater compressive value and increases at 7, 14, and 28 days of age compared to normal concrete [23].

In the context of highway bridge construction, reinforced concrete structures are gaining popularity due to the increasing traffic requirements, with frequently used soil retaining walls showing hydraulic characteristics according to specific soil conditions other research suggests designs that can be adjusted to improve the performance of these structures [24].

Different types of retaining walls, such as cantilever, gravity, semi gravity, and counterfort (see **Fig. 3**) [25], require precise calculations to ensure stability. Cantilever type retaining walls [26-29], for example, use thin spans and reinforced concrete base plates, offer good performance in withstanding large lateral pressures, but require special attention to design planning and material selection to avoid damage due to earthquake loads. Meanwhile cantilever walls can be optimized with the addition of reinforcing elements, such as geogrids, to increase resistance to lateral soil pressure [30-32].

Gravity-type retaining walls, which are made of plain concrete or masonry pairs, depend on the weight of the material to hold the soil behind them [33]. Semi gravity walls, with the use of additional steel, offer the advantage of smaller dimensions and additional strength without significantly increasing weight and the other suggests that semi-gravitational walls can reduce material costs while still providing adequate stability in diverse soil conditions [34].

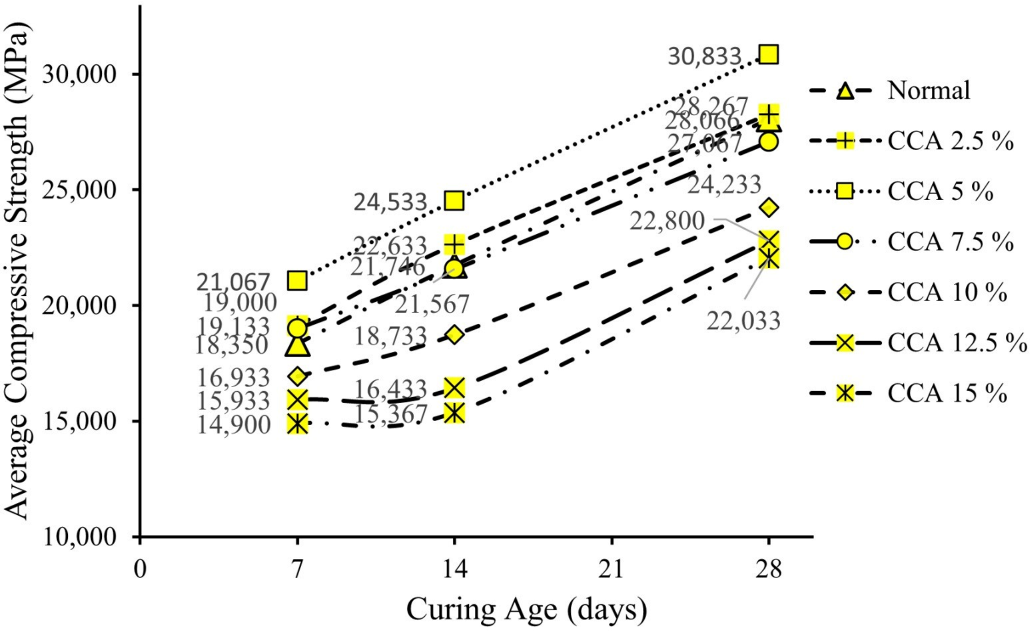

Figure 2. CCA mixed compressive strength versus age (days)

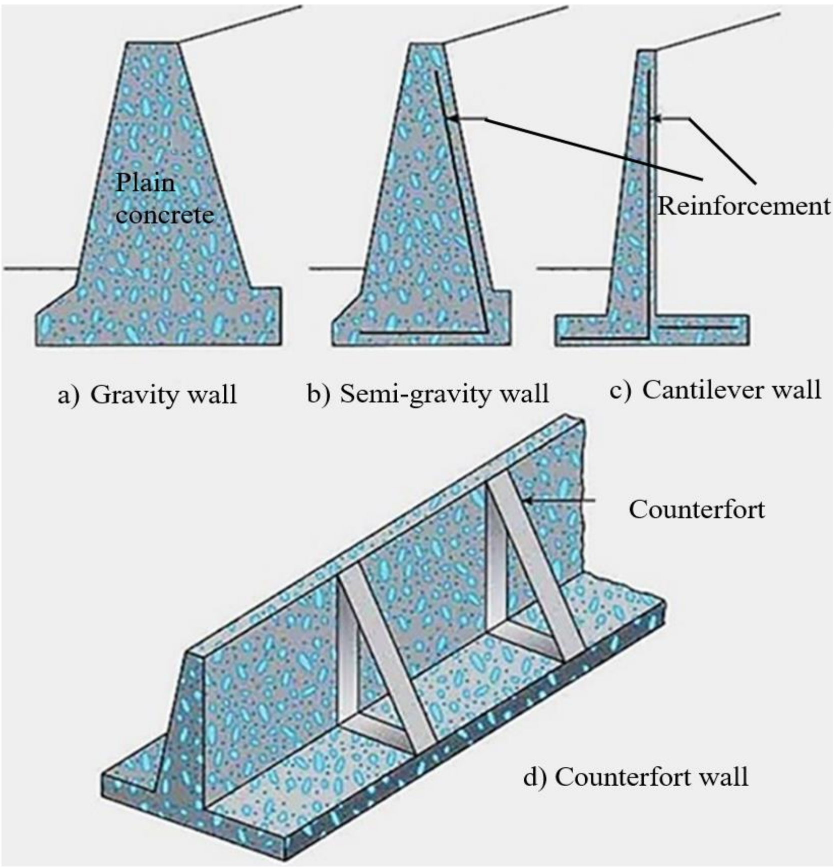

Figure 3. Retaining wall [25]

Retaining walls of the counterfort type bear resemblance to cantilever walls, but they include counterfort elements that more effectively distribute soil pressure. The presence of these counterforts enhances the stability of retaining walls in unstable soils, particularly in areas prone to high liquefaction during seismic events [35]. These elements not only reduce deformation of the wall but also bolster its overall structural integrity. Measurements obtained from sensors indicate that a combination of piles with varying rigidity in the backfill can significantly mitigate wall displacement caused by liquefied soil [36]. Additionally, a novel method for calculating active seismic earth thrust in cantilever-type retaining walls, whether featuring a short or long heel, has been introduced through a pseudo-static approach. The outcomes of this method have been compared against those derived from conventional techniques and experimental studies. The findings reveal that both the thickness of the foundation and the length of the heel play critical roles in determining the active seismic earth pressure coefficients [29].

The fineness test of corn cob ash is conducted to enhance the utilization of agricultural waste as a valuable resource in the construction sector. Data from the test indicates that the particle fineness of the ash significantly influences the strength of the concrete produced [7, 37-39]. Incorporating materials like coarse and fine aggregates along with pozzolan derived from corn cob ash into concrete mixes enhances the strength and mechanical properties of the concrete [20, 40-42], showcasing the potential of using locally sourced materials in sustainable construction. Although interlocking brick systems provide greater construction efficiency, speed, and improved earthquake resistance compared to traditional structures, there are certain challenges associated with cost-effectiveness and dust generation during cutting.

2. Materials and Methods

To evaluate the possible use of agricultural waste, in particular corn cob ash, as an addition to concrete mixtures. The focus of this study is to evaluate the performance of interlock concrete through testing of compressive strength, water absorption, and lateral shear strength on the resulting concrete.

Primary data were collected through a series of direct tests on test cylinders in **Fig. 4** containing corn cob ash, as well as observations in the process of making interlock concrete samples. The interlock concrete test specimens were cured for 28 days, then arranged into walls as depicted in Fig. 5 with wall dimensions of 15×75×47 cm.

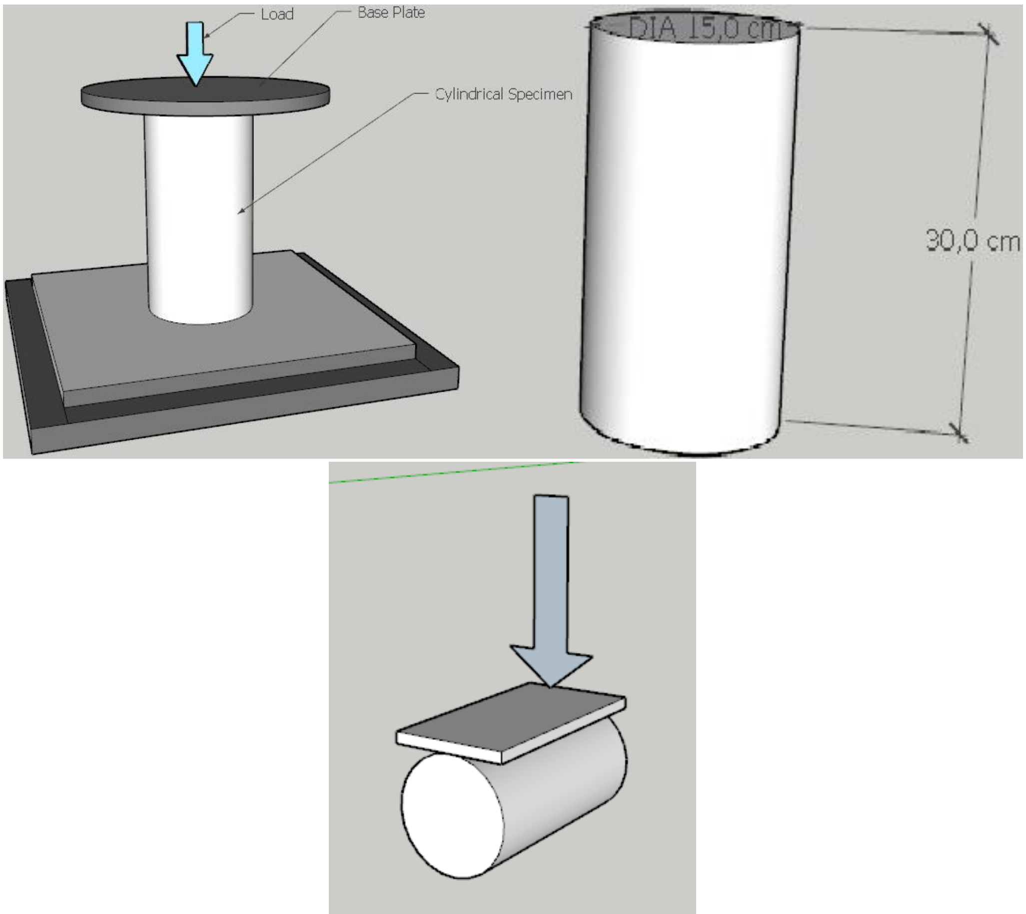

Figure 4. Cube-shaped specimens for compressive and tensile strength tests [25]

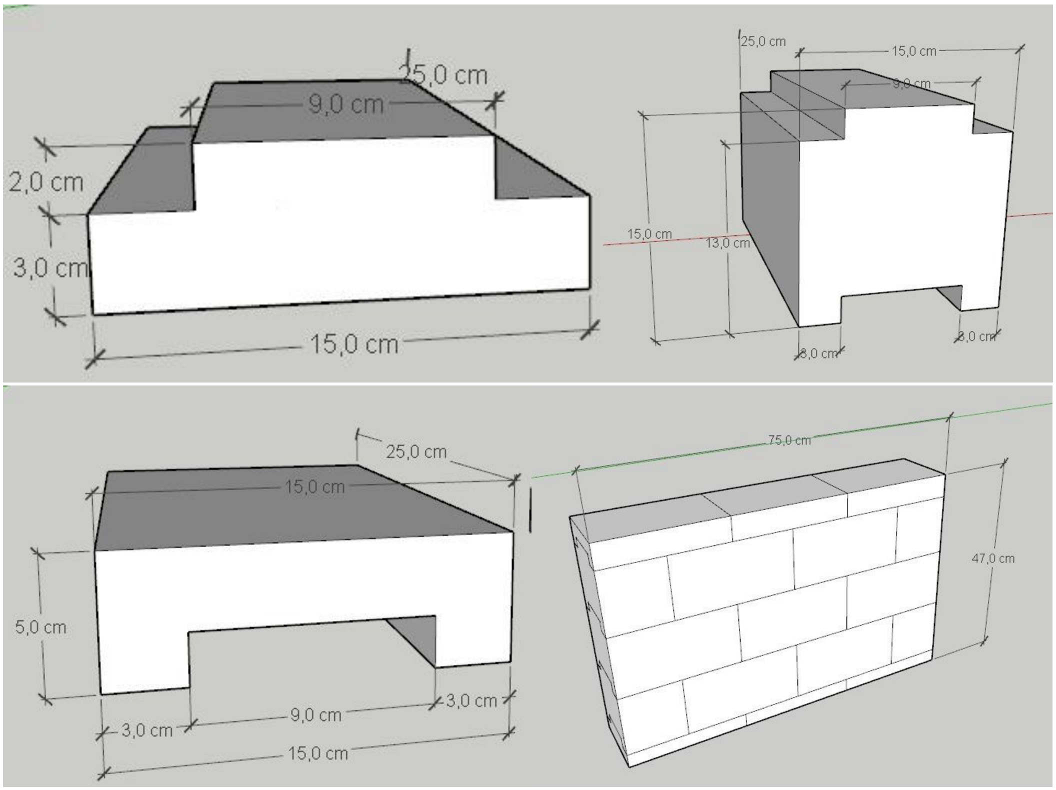

Figure 5. Concrete specimen and interlocking wall

The initial test involves testing the physical properties of the aggregate, which includes evaluation of weight held on each sieve, gradation, strength, wear, shape, and texture to ensure the aggregate quality. The data shows the size distribution of coarse aggregate, crucial for determining its suitability for construction applications like concrete and asphalt. Grading analysis ensures the aggregate is sized correctly to provide the desired strength and stability. **Table 1** displays the weight retained on each sieve size, illustrating the distribution of coarse aggregate particles. Most are retained on larger sieves, while fewer remain on smaller ones. A high fineness value indicates coarse aggregate retention on larger sieve sizes. **Fig. 6** shows whether the particle size distribution meets SNI T-15-1990-03 standards, with the black line indicating acceptable use if within the blue boundaries.

On the other hand, the fine aggregate gradation shows the particle size of the fine aggregate to be used in the interlocking concrete mixture. The results of the test specimen weight test on various sieve sizes are shown. From the sieve size of 9.5 - 4.75 mm, the weight of the test piece was recorded at 2.90 g, while for the sieve size of 4.75 - 2.36 mm, the weight was 33.40 g. The sieve size of 2.36 - 1.18 mm has a specimen weight of 124.60 g, and the sieve of 1.18 - 0.60 mm indicates the largest weight of 159.70 g. For a 0.60 - 0.30 mm sieve, the specimen's weight is 114.30 g, while a 0.30 - 0.15 mm and a 0.15 - 0.00 mm sieves notes 1.00 g and 67.80 g respectively. The specimen weight is 503.70 g with a fineness figure of 2.76.

Table 1. CCA content of specimens

No	Specimen	CCA content (%)	Age	Total
			28 days	
1	Cylinder	0%	6	6
2	Cylinder	2%	6	6
3	Cylinder	3%	6	6
4	Cylinder	4%	6	6
5	Interlocking Wall	Top	6	34
		Middle	14	
		½ Middle	8	
		Bottom	6	
Total				58

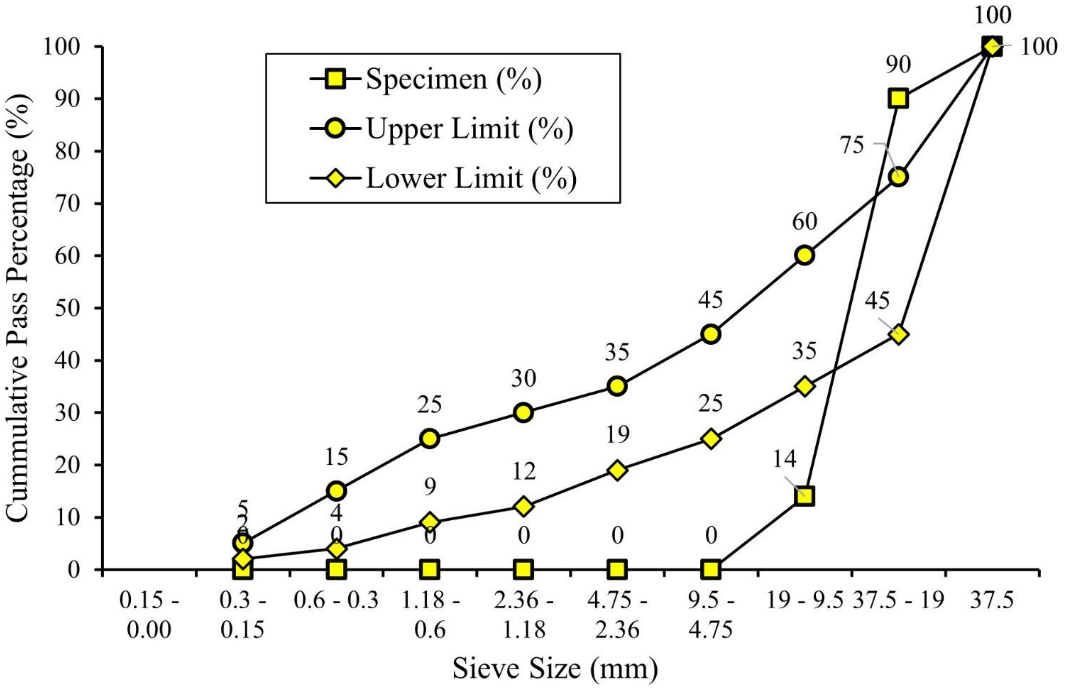

Figure 6. Coarse aggregate gradation result

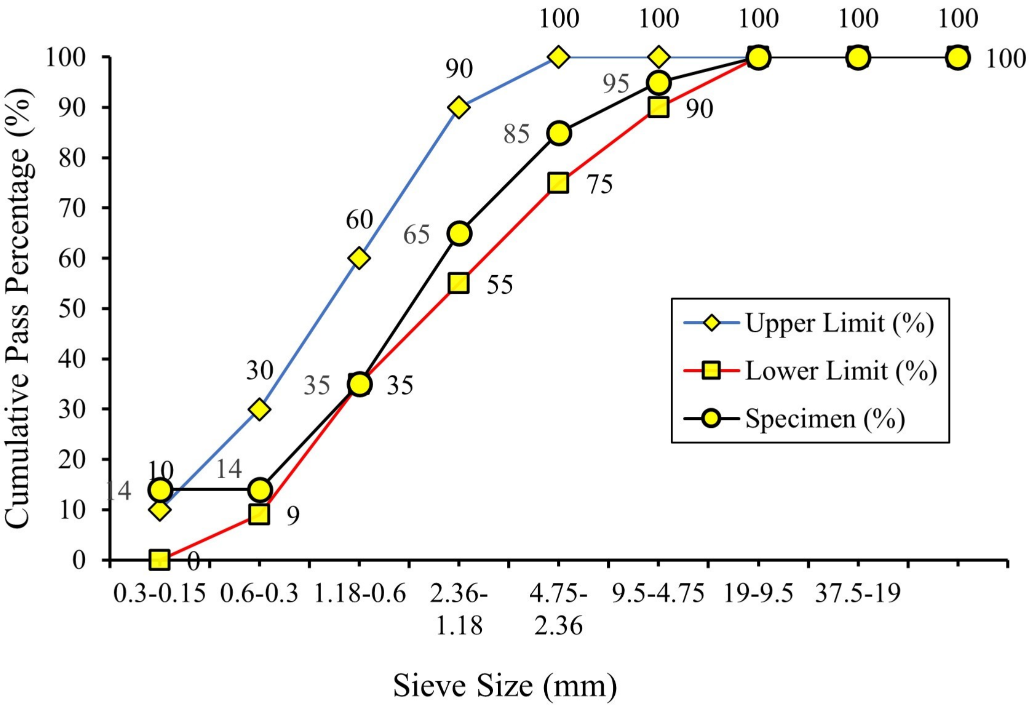

Figure 7. Fine aggregate gradation result

Fig.7 illustrates the cumulative pass percentage of fine aggregate particle sizes as they correlate with sieve size. Additionally, corn cob ash, derived from the combustion of corn cobs, is subjected to testing to determine its physical properties, including fineness, specific gravity, and oxide composition, to evaluate its viability for use in interlocking concrete. The fineness test results will indicate the distribution of corn cob ash particle sizes across various sieve levels, revealing the proportion of coarse and fine particles within the sample. According to ASTM standards, cement particles passing through sieve No. 200 (Ø 0.075 mm) should exceed 78%, while sieve No. 100 must allow 100% passage. The ash retained on the No. 100 sieve is 44%, falling short of the ASTM standard that requires complete passage. On the No. 200 sieve, 20% of the ash is retained, meaning 80% passes, just meeting the ASTM minimum standard of 78%, although this is a marginal compliance. Consequently, the corn cob ash fails to meet the ASTM fineness requirement for the No. 100 sieve and only minimally satisfies the No. 200 standard. As a result, only the corn cob ash that passes through the No. 100 sieve will be incorporated into the interlock concrete mix, while the ash particles that do not pass will be excluded or discarded.

The average specific gravity of corn cob ash is 2.00, whereas the specific gravity of cement, according to ASTM standards, typically ranges from 3.12 to 3.16. This study utilizes a concrete cylinder measuring 15 x 30 cm as the specimen for compressive strength testing, with detailed specifications provided in **Table 1**.

Aggregate testing involves various procedures, including determining moisture content, specific gravity, water absorption, gradation, organic matter content, and hardness, each utilizing specialized equipment.

Concrete mix design is conducted in accordance with the SNI 03-2834-2000 standard, which emphasizes critical factors such as the water-cement ratio, workability (slump), aggregate size, and cement content. The mixing process begins with coarse aggregate being combined in a mixer, followed by the gradual addition of corn cob ash, ensuring thorough integration. A slump test is performed to verify the concrete's consistency. After casting, meticulous curing is essential during the hardening phase. Additionally, tensile and shear strength tests are conducted on interlock concrete walls, with precise specimen measurement and marking to guarantee accuracy. The careful placement of specimens and use of equipment are crucial to ensuring reliable test results.

3. Results and Discussion

In this study, a thorough series of tests was conducted to evaluate the physical properties of aggregates and to examine the influence of corn cob ash on the characteristics of concrete. The investigation commenced with an assessment of the moisture content in both coarse and fine aggregates, essential for ensuring the precise water-cement ratio in concrete mixes.

The moisture content results for the coarse aggregate, indicate an average moisture content of 1.22%. According to SNI 1971 (2011), this value is significantly below the recommended maximum moisture content range of 3–5%. This low moisture content ensures that there is no excess water present, which could otherwise alter the proportions of the concrete mix.

The moisture content of the fine aggregate, was determined to be 4.07%. According to SNI 1971 (2011), the acceptable moisture content for fine aggregates ranges from 3–5%, depending on the material's condition. In this case, the 4.07% value falls within the acceptable range, ensuring that the resulting concrete mix remains consistent with the standards.

The study also revealed that the coarse aggregate had an average moisture content of 1.22%, while the fine aggregate registered 4.07%, both within the acceptable limits outlined in industry standards. Maintaining these moisture levels is crucial, as they directly influence the mix’s consistency and strength.

Additionally, the study assessed the bulk density of the aggregates, which refers to the mass of aggregates relative to their volume. This parameter is critical, as it impacts the overall density and compactness of the concrete. The test results indicated that both fine and coarse aggregates exhibited densities that are optimal for producing concrete with the desired strength.

The specific gravity and water absorption properties of coarse aggregates were evaluated for two test specimens (Test Specimen I and Test Specimen II) in accordance with SNI 1969 (2016) standards, as detailed in the table above. The results from both the specific gravity and water absorption tests comply with the established standards, thereby confirming the suitability of these coarse aggregates for use in concrete mixtures.

The specific gravity and water absorption results for fine aggregates, evaluated according to SNI 1970 (2016) standards. These results indicate that the fine aggregates meet the required criteria for use in concrete mixtures.

Furthermore, the research delved into the properties of corn cob ash, with a particular focus on its fineness and chemical composition—key factors in its potential as a supplementary cementitious material. The fineness test demonstrated that a significant portion of the ash particles was smaller than 45 microns, indicating its effectiveness as a pozzolan. This material, when combined with lime, can form cementitious compounds. Additionally, aggregate content weight testing was conducted to assess the material's quality.

The chemical analysis using XRF technology confirmed that the corn cob ash (CCA) contains significant levels of potassium oxide (K_2O) at 66% and silicon dioxide (SiO_2) at 22.5%. Both compounds are advantageous for enhancing the hydration process in concrete, underscoring the quality of CCA, which is the primary focus of this study. The subsequent XRF test results are presented in **Table 2**, which details the chemical composition percentages in corn cob ash. The material properties and characteristics are largely influenced by these chemical constituents. In construction applications, the 22.5% SiO_2 content in CCA contributes to improved mechanical strength and corrosion resistance. Additionally, the high K_2O content at 66.0%, significantly surpassing that found in conventional cement, suggests its potential use as an additive in concrete or mortar due to its impact on rheological properties and material strength.

Table 2. XRF test results of corn cob ash

Chemical compound	content (%)
SiO_2	22.5
P_2O_5	4.3
K_2O	66.0
TiO_2	0.1
MnO	0.16
Fe_2O_3	1.67
CuO	0.11
ZnO	0.41
Rb_2O	0.70
Y_2O_3	0.0
MoO_3	3.7
BaO	0.2

In the concrete mixture experiment, three different mixtures with varying water, cement, and corn ash ratios were tested. The third mixture proved to be the most effective, achieving a slump value of 65 mm, which indicates good workability, and a compressive strength of 17 MPa on day 3, projected to reach 42 MPa after 28 days.

To achieve the optimal concrete mixture with the addition of CCA, the experiment was conducted three times. In the first attempt, an error occurred due to excessive water addition, leading to overly high workability and a significant reduction in compressive strength, resulting in a mixture that was too dilute and failed to meet the required standards. In the second experiment, the water proportion was adjusted, but the compressive strength still fell short of the target.

After evaluating and revising the previous two experiments, the third trial was conducted with more precise measurements and careful selection of materials. The trial mixture, utilizing a Cement Water Factor (CWF) of 0.45, resulted in a slump value of 6.5 mm, indicating appropriate workability. On day 3, the concrete achieved a compressive strength of 17 MPa and a tensile strength of 2.03 MPa. The projected compressive and tensile strengths at 28 days are 42 MPa and 5.01 MPa, respectively. These results confirm that the concrete mixture meets the established standards.

When calculating material requirements for a cylindrical specimen concrete mixture, it is crucial to account for potential material loss. This is managed by including an additional cylindrical test specimen in the calculation. Thus, if concrete is prepared for cylindrical test specimens, the material requirement is determined as the total needed for the specified number of specimens plus one additional specimen to ensure sufficiency, even if minor losses occur during mixing or casting.

For each content, 4 test specimens are required for compressive strength testing and another 4 for tensile strength testing. Out of these, only 3 specimens are tested, with the remaining one reserved as a backup in case of damage. Considering the material loss tolerance, one extra cylindrical test specimen is added, bringing the total number of test specimens per content to 10, including reserves and loss tolerance.

Based on the results of the test mix design, the material requirements needed to produce a 1 m ^{3} cylindrical test specimen. For interlock concrete test specimens, a loss tolerance of 10% of the specimen's volume is applied. To calculate the necessary material, the volume of the interlock test specimen is multiplied by 10%, after which the material requirements can be determined.

Using a similar approach as the cylindrical test specimens, we can calculate the material needs for interlock test specimens, which have been designed and calculated for wall assemblies. For interlock test specimens with the codes "Bottom" and "Top," 6 test specimens are required for each. For specimens with the "Middle" code, 14 specimens are needed, while 8 specimens are required for those with the "1/2 Middle" code.

Since the most optimal ash content for the interlocking specimens is yet to be determined, it is necessary to calculate the ash requirements for all potential contents. These results indicate that this mix is highly suitable for construction projects that demand concrete with both high strength and excellent workability. The study also established the material requirements for producing cylindrical and interlocking concrete specimens, ensuring that the mix design is optimized for practical construction applications (**Table 3**).

Table 3. Mix design for a 1 m^3 cylinder specimen

Material	Total Requirement in 1 m^3 (kg)				
	0%	1%	2%	3%	4%
Sand	38.50	38.50	38.50	38.50	38.50
Gravel	55.79	55.79	55.79	55.79	55.79
Water	9.99	9.99	9.99	9.99	9.99
Cement	24.14	24.14	24.14	24.14	24.14
CCA		0.0241	0.0483	0.0724	0.966

3.1. The Slump Results

After testing the slump value of the concrete mixture with various proportions of corn cob ash (CCA) added, the results demonstrated significant contents depending on the quantity and type of ash used. Corn cob ash was tested in different ratios to identify the most optimal mix for achieving the desired slump in the concrete. The values of the slump for each CCA content in the concrete mix are presented in Fig. 8.

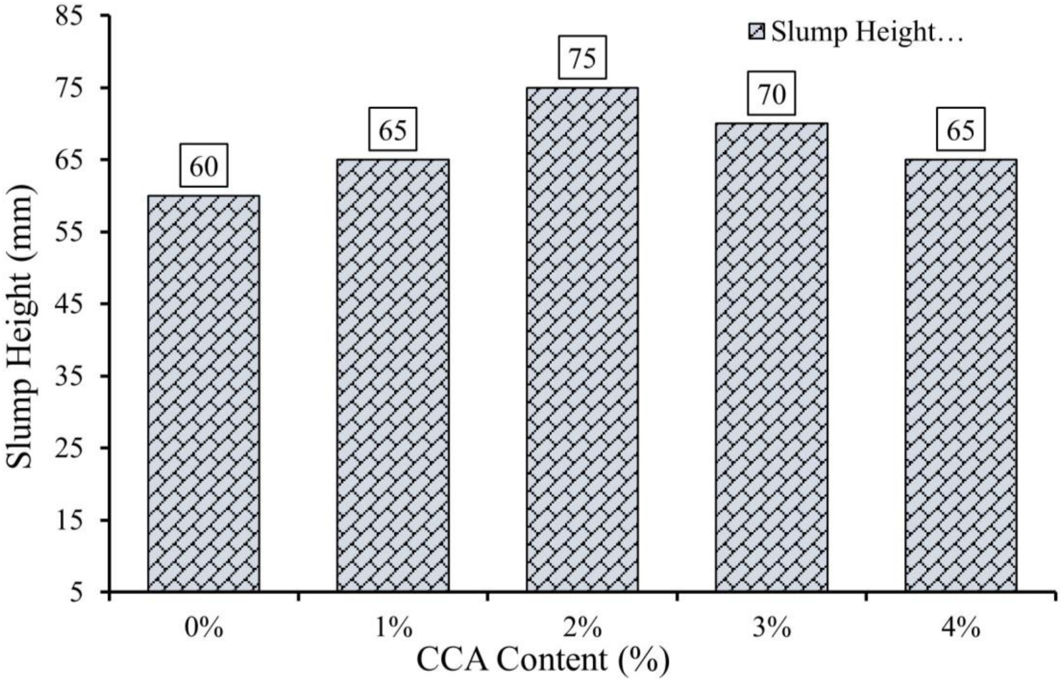

Figure 8. Slump value versus CCA content

If the slump value after the addition of corn cob ash falls below the lower limit of the planned slump (60 mm), then adjustments, such as the gradual addition of water, are required to ensure the consistency of the concrete meets the expected standards for the specific construction application.

From these data, it can be concluded that the addition of corn cob ash in the concrete mixture can significantly affect the height of the slump. In the 0% CCA content, the slump value reaches 60 mm, then in the 1% and 2% CCA contents, the slump value increases gradually, but in the 3% and 4% CCA contents, it decreases again. From the data above, the slump value is stated to meet because it is not less than the planned slump value, which is 60–180 mm.

3.2. Air Content Results

The quality and durability of concrete are significantly influenced by its air content, which is assessed through air content testing. The amount of air entrained in the mix impacts the physical and mechanical properties of concrete, including its resistance to freeze-thaw cycles and corrosion. The air content values for concrete with varying amounts of corn cob ash (CCA) are presented in the **Fig. 9**.

3.3. Density Results

After testing the weight value of the concrete mixture, the results highlighted the density and quality of the concrete with varying content of corn cob ash (CCA). The weight or density of the concrete mix directly influences the strength and stability of the structure. The weight values of the concrete mix with different CCA contents are presented in Fig. 10.

It can be shown from Fig. 10 that the weight of the concrete mix with 0% CCA content is 2.45 kg. For the 1%, 3%, and 4% CCA contents, the weight is 2.52 kg, while the 2% CCA content has a weight of 2.48 kg.

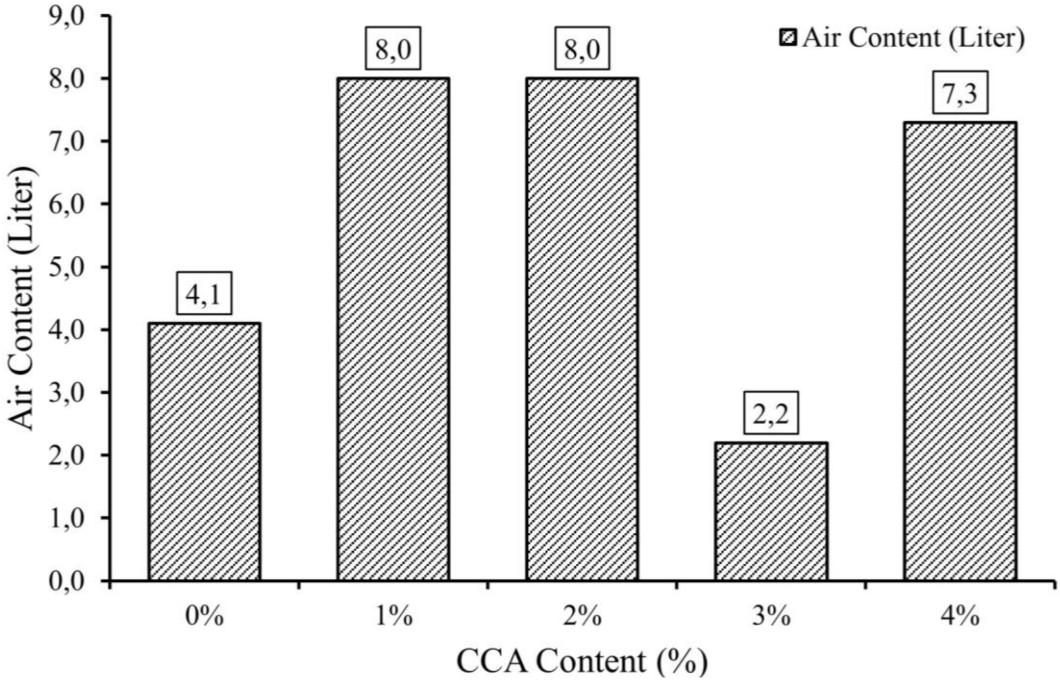

Figure 9. Air content versus CCA content

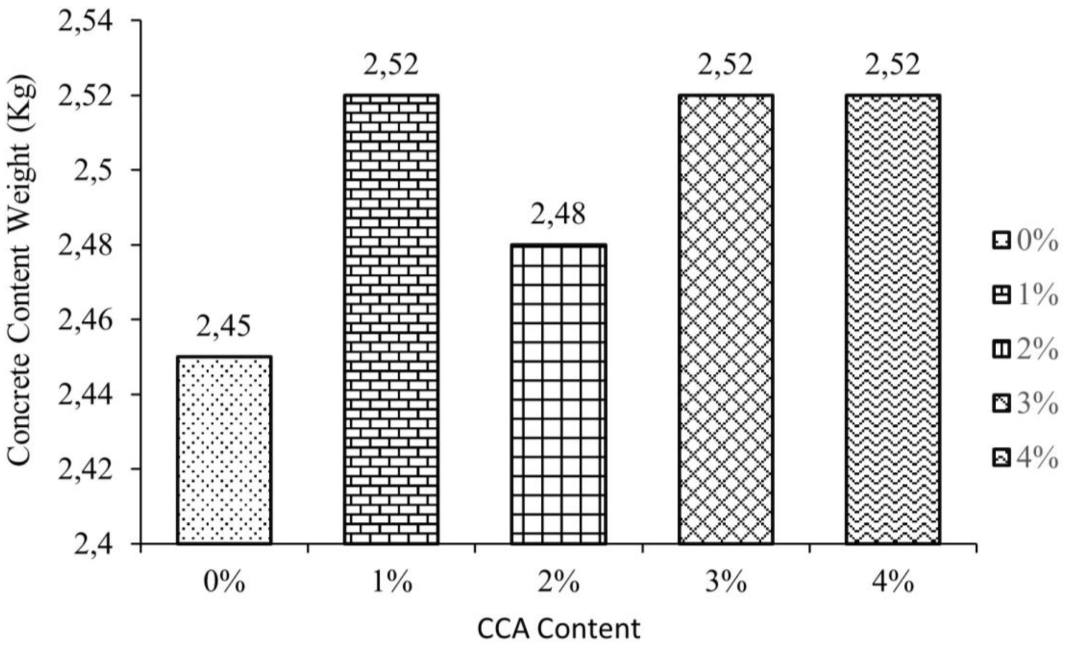

Figure 10. Density versus CCA content

3.4. Compression Test Results

The compression test results for cylindrical specimens with corn cob ash (CCA) mixtures are presented here. The purpose of this test is to determine the compressive strength of the cylindrical specimens, based on the compositions which detail the properties of the test pieces. Each specimen is subjected to a compression test to assess its ability to withstand load before failure occurs.

Based on the Fig. 9, the air content test results revealed that for the 0%, 1%, 2%, 3% and 4% CCA contents, the air content was measured as 74.1 liters, 8 liters, 8 liters, 2.2 liters, and 3 liters respectively.

A compressive strength evaluation was conducted on cylindrical concrete specimens incorporating varying proportions of Corn Cob Ash (CCA): 0%, 1%, 2%, 3%, and 4%. The specimens were tested at 28 days of curing. Data analysis reveals a notable reduction in compressive strength, specifically a 16.9 MPa decrease, upon the inclusion of 1% CCA. However, as the CCA content increased to 2%, 3%, and 4%, there was a significant recovery in compressive strength, with values approaching those of the control mix (0% CCA) at 30.3 MPa.

Fig. 11 illustrates that CCA incorporation influences concrete's compressive strength, despite the consistent curing period of 28 days. The data indicates that increasing the CCA percentage from 0% to 4% generally leads to a reduction in average compressive strength. Given that the concrete mix with 2% CCA demonstrates the highest compressive strength, it can be concluded that a 2% CCA content provides an optimal mix for interlocking specimens.

3.5. Tensile Test Results

This test was conducted to evaluate the tensile strength of concrete incorporating varying proportions of corn cob ash (CCA). Fig. 12 presents the tensile strength results for each concrete specimen, highlighting the impact of different CCA mixtures.

Tensile strength testing was conducted on concrete samples with varying percentages of Corn Cob Ash (CCA), specifically 0%, 1%, 2%, 3%, and 4%. All samples were tested at a uniform age of 28 days, as indicated by the blue bars of equal height in each category, reflecting the consistent curing time across all contents.

The results indicate that the average tensile strength decreased as the CCA content increased. The control sample, with 0% CCA, exhibited the highest tensile strength, reaching approximately 3.6 MPa. The graph demonstrates that the incorporation of CCA into the concrete mix negatively impacts its tensile strength. Despite maintaining a constant age of 28 days, increasing the CCA percentage from 0% to 4% leads to a reduction in average tensile strength.

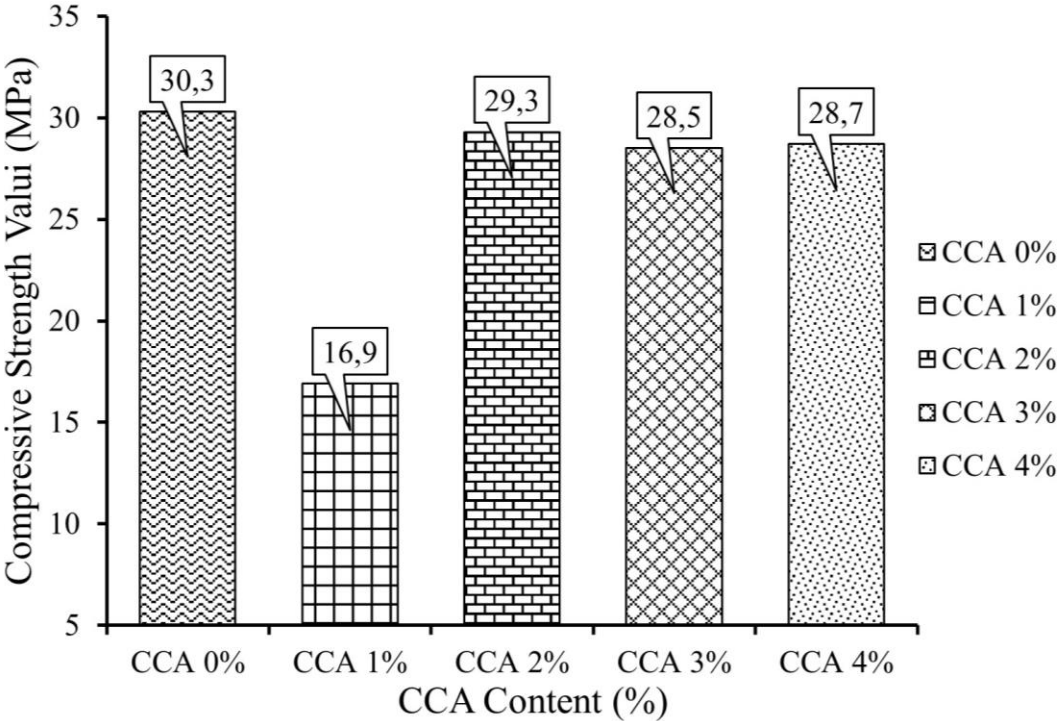

Figure 11. Compressive strength versus CCA content

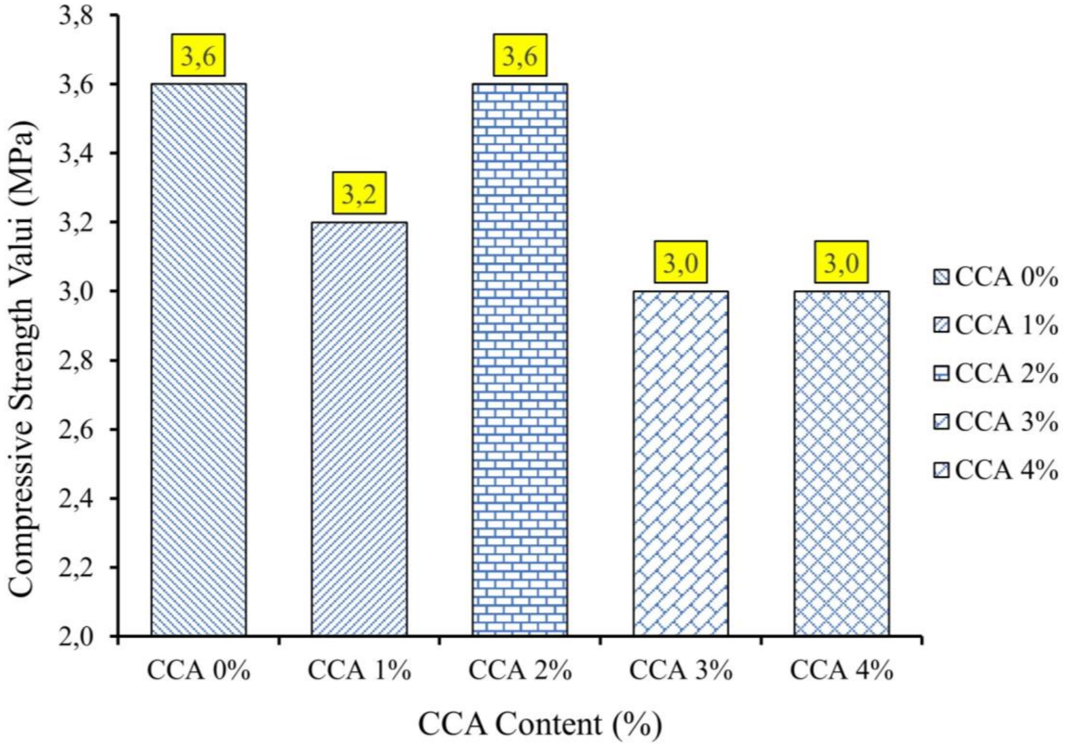

Figure 12. Tensile strength versus CCA content

3.6. Interlocking Wall Shear Test Results

The material requirements for interlocking concrete specimens, the specific ash contents used for the interlock wall test pieces were not initially detailed. However, it has been established that the optimal compressive strength, 29.3 MPa, was achieved with a 2% Corn Cob Ash (CCA) mixture. Consequently, the interlock wall test specimens were prepared using a 2% CCA mix.

The test results indicate that the addition of CCA to the concrete mix influences the shear test behavior of the interlock wall. Fig. 13 presents the corresponding values, illustrating the deflection relative to the load applied to the interlocking wall specimens.

From Fig. 13, it is evident that the interlocking wall remains within the elastic range under a load of 0 to 105.4 kg, showing no measurable deformation. Deformation begins at a load of 305.4 kg, with an initial deflection of 0.004 mm, marking the onset of deformation in the wall. As the load increases, deflection gradually rises. At 805.4 kg, the deflection reaches 0.025 mm, and with a load of 905.4 kg, it sharply escalates to 0.057 mm. When the load hits 1005.4 kg, deflection significantly increases to 0.193 mm, indicating that the interlock wall is experiencing more pronounced deformation. At 1105.4 kg, the deflection reaches 0.294 mm, reflecting a notable increase in strain.

As the load reaches 1205.4 kg, deflection drastically rises to 0.677 mm, and by 1305.4 kg, it reaches 0.869 mm. The deformation continues to intensify with further loading; at 1405.4 kg, deflection becomes 1.076 mm, and by 1505.4 kg, it increases to 1.268 mm. These measurements suggest that the interlock wall is nearing its critical condition and approaching its load-bearing capacity. Under a load of 1605.4 to 1705.4 kg, deflection grows to 1.452 mm, and at 1805.4 kg, it increases to 1.576 mm. When the load reaches 1905.4 kg, deflection jumps significantly to 4.108 mm, signaling the onset of structural failure in the interlocking wall. At its peak load of 2005.4 kg, the deflection reaches 4.216 mm, indicating that the wall has undergone substantial deformation and has exceeded its failure limit.

Fig. 14 illustrates that under a load of 0 to 205.4 kg, the interlock wall remains in the elastic zone without any observable deformation. The first noticeable deflection occurs at a load of 305.4 kg, registering a value of 0.623 mm. As the load increases to 405.5 kg, the deflection rises to 1.185 mm, indicating more pronounced deformation.

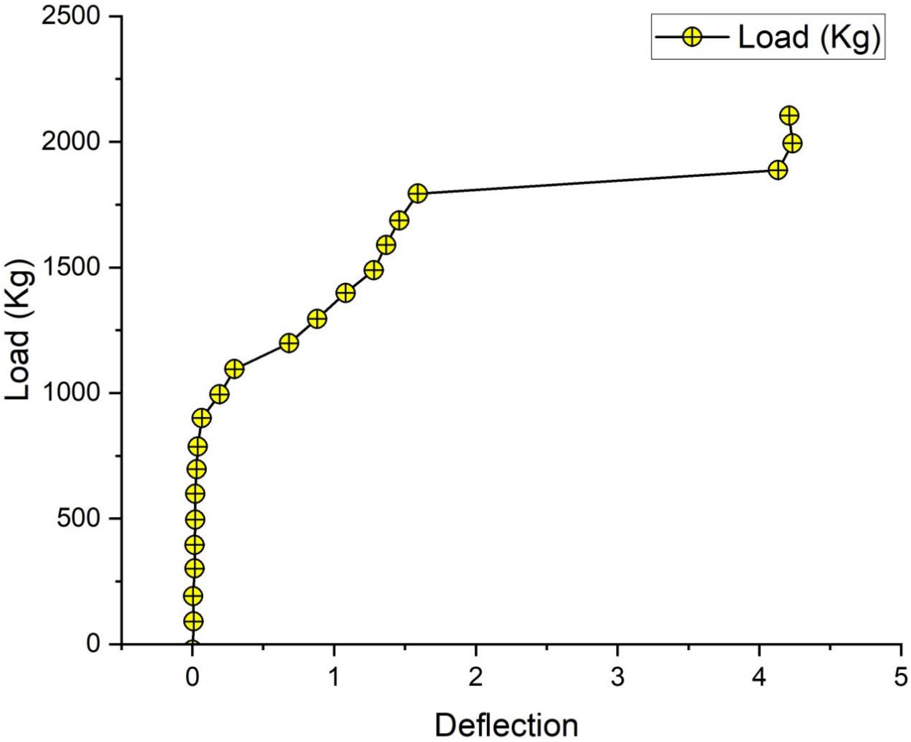

Figure 13. Shear test result of the wall specimen 1

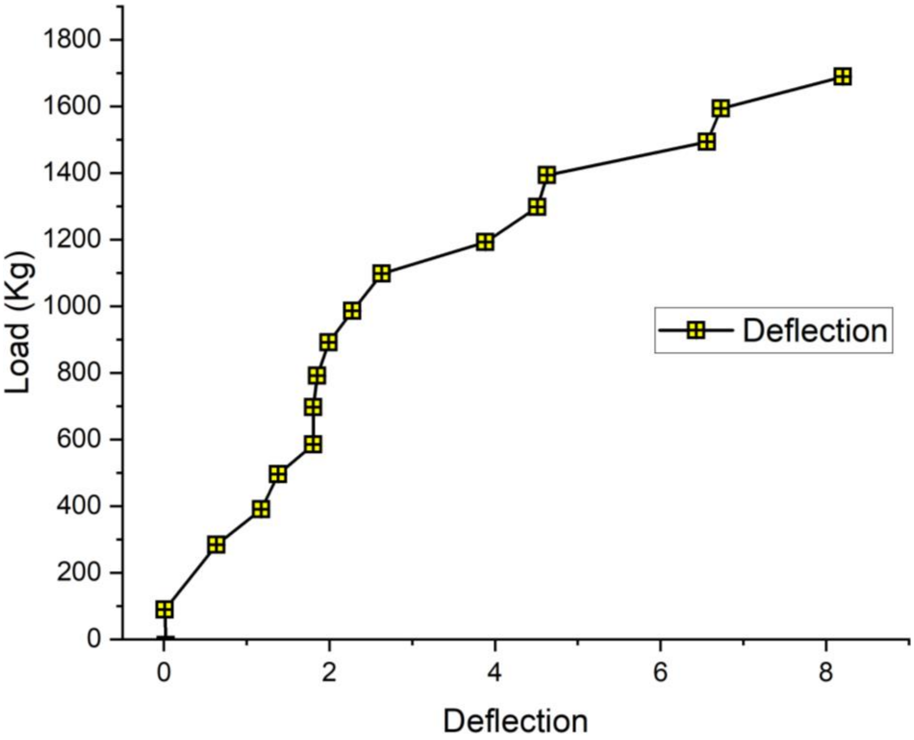

Figure 14. Shear test result of the wall specimen 2

The deflection continues to increase gradually with further loading; at 605.4 kg, the deflection reaches 1.806 mm, and at 705.4 kg, it slightly increases to 1.808 mm, showing that the interlock wall is still effectively bearing the load. However, at 805.4 kg, the deflection increases to 1.857 mm, indicating more significant deformation.

When the load reaches 905.4 kg, deflection sharply rises to 1.976 mm. At 1005.4 kg, the wall undergoes substantial deformation with a deflection of 2.286 mm. This trend continues as the load increases to 1105.4 kg, where deflection reaches 2.617 mm. At 1205.4 kg, deflection escalates to 3.86 mm, and at 1305.4 kg, it further increases to 4.496 mm.

By 1405.4 kg, the deflection reaches 4.613 mm. At 1505.4 kg, the wall enters a critical state, with deflection reaching 6.521 mm. Finally, at a load of 1605.4 kg to 1705.4 kg, the deflection reaches 8.182 mm, indicating that the wall has reached its failure point.

The average deflection indicates that the interlocking wall begins to experience significant deformation at a load of approximately 1005.4 kg, with deflection sharply increasing under higher loads until structural failure occurs at 2005.4 kg. This underscores the critical importance of establishing load limits in the design of interlocking walls to ensure the stability and integrity of the structure. Table 4 presents the results from the shear tests conducted on specimens 1 and 2, also see **Fig. 15.**

The average shear stress of 57328 kg/m^2 or 57.33 ton/m^2 reflects the interlocking wall's capacity to withstand shear loads prior to failure. These values are crucial for confirming that the interlock wall possesses adequate strength for its intended application and for determining the safe limits of permissible shear stresses.

The research also revealed that incorporating up to 10% corn cob ash by weight of cement enhanced the concrete's compressive strength by up to 5% compared to conventional concrete without CCA ash. However, surpassing this 10% threshold resulted in a decline in strength, highlighting the need for careful management of ash content to avoid compromising the concrete's performance.

Table 4. Properties and shear stress of interlocking wall

properties	Specimen I	Specimen II	Unit
Shear Force (D)	1022.4	869.45	kg
Static Moment (S)	0.000938	0.000938	cm^3
Cross-sectional width (b)	0.25	0.25	m
Cross section height (h)	0.15	0.15	m
Moment of Inertia (Ix)	7.031E-05	7.031E-05	cm^4
Shear stress (τ)	61963.64	52693.64	kg/m^2
	61.96	52.69	ton/m^2

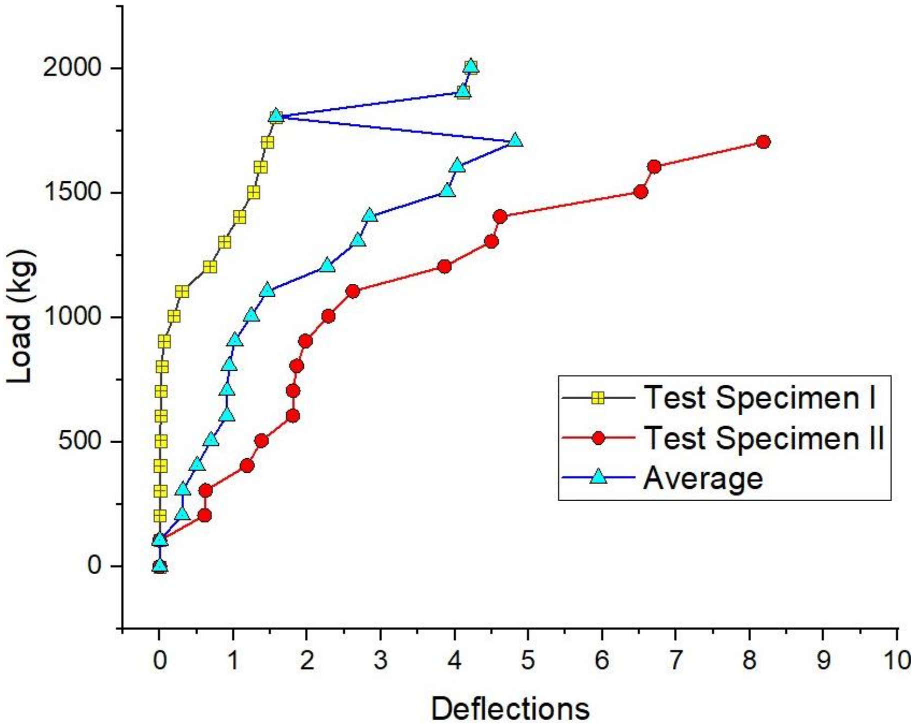

Figure 15. Shear test result

4. Conclusions

Based on the research problem, objectives, and conditions observed throughout the study, the findings regarding the use of corn cob ash (CCA) as an additive in interlock concrete for bridge wingwall structures are as follows:

1. Specimen 2, which incorporated a 4% CCA content and weighed 12.7 kg, exhibited the highest compressive strength at 33 MPa. However, the concrete mix with a 2% CCA content achieved the highest average compressive strength of 29.3 MPa, with an average weight of 12.7 kg. In terms of splitting tensile strength, specimen 3, containing a 2% CCA content and weighing 12.5 kg, recorded the highest tensile strength of 3.8 MPa. The 2% CCA content also produced the highest average splitting tensile strength of 3.6 MPa, with a 12.5 kg average weight.
2. For the interlocking wall, specimen 1 demonstrated a shear stress value of 61.96 tons/m^2 under a load of 2044.8 kg, while specimen 2 exhibited a shear stress value of 52.69 tons/m^2 under a load of 1738.89 kg. The calculated average shear stress for the interlock wall was 57.33 tons/m^2, with an average load of 1891.84 kg.
3. The study shows that adding CCA in varying proportions (up to 4%) enhances the compressive, tensile, and shear strength of the concrete blocks. A 2% CCA mix was identified as the optimal composition, striking a balance between material efficiency and strength. This research supports the use of CCA to reduce the environmental impact of construction while maintaining structural integrity, advocating for broader adoption of eco-friendly alternatives in civil engineering projects.
4. Corncob ash (CCA) shows potential in enhancing the sustainability of concrete production, particularly through its pozzolanic and micro-filling effects, although challenges remain in optimizing its mechanical properties due to its permeable nature.
5. The versatility of CCA, alongside its ability to reduce environmental impact, aligns well with circular economy principles, offering a sustainable alternative for a variety of construction applications, especially in regions with abundant corn production.
6. As research on CCA and corncob-based materials expands, further studies are essential to understand their long-term performance and optimize their use in advancing eco-friendly construction practices, contributing to global sustainability goals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this article.

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