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Investigating the waterproofing properties of concrete made with rice husk ash and corn cob ash

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Abstract

The construction industry constantly strives to enhance the durability and water resistance of concrete structures, particularly in regions with varied climatic conditions like Nigeria. Traditional waterproofing methods often depend on expensive and non-sustainable materials, highlighting the need for more eco-friendly and cost-effective alternatives. This project investigates the potential of Rice Husk Ash (RHA) and Corn Cob Ash (CCA) as sustainable additives to improve the waterproofing properties of concrete. A comprehensive literature review underscores the importance of waterproofing in construction and the promising properties of RHA and CCA. RHA, derived from rice husk, exhibits pozzolanic characteristics that enhance concrete durability. Meanwhile, CCA, produced from corn cobs, helps reduce concrete porosity and improve moisture resistance. The experimental procedures involved collecting and preparing RHA and CCA and then incorporating these additives into concrete mixtures in varying proportions. All specimens were prepared using a mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) and a water-cement ratio of 0.6. Slump tests and water absorption tests were conducted to evaluate the workability and moisture resistance of the concrete mixtures. Slump test results indicated a slight reduction in workability with higher proportions of RHA, though all specimens maintained acceptable slump values. Water absorption test results showed that concrete specimens containing RHA and CCA had significantly lower water retention compared to the control group. Notably, the mixture with 40% RHA and 60% CCA exhibited exceptional moisture resistance, showing no water retention after 28 days of curing. The findings suggest that a 40% RHA - 60% CCA mixture is the most suitable proportion for enhancing the waterproofing properties of concrete without significantly compromising workability. This study concludes that RHA and CCA are viable, sustainable alternatives for waterproofing concrete, offering benefits such as reduced material costs, environmental sustainability, and improved concrete performance. Further research is recommended to optimize these proportions and validate their effectiveness in real-world construction applications. This project contributes to sustainable construction practices by utilizing locally sourced agricultural waste products, thereby promoting environmental conservation and economic efficiency in the construction industry.

Keywords: Waterproofing; Concrete; Rice Husk Ash; Corn Cob Ash

1. Introduction

Concrete is a composite material widely utilized in construction for its strength, durability, and adaptability. Composed primarily of cement, aggregates (such as sand, rock, or gravel), water, and admixtures, concrete is fundamental to civil engineering projects. It remains the preferred material for constructing foundations, tie beams, ground slabs, and various subterranean and coastal structures due to its accessibility, affordability, exceptional durability, moldability, and the ability to be produced using industrial waste with minimal energy consumption (Bamigboye et al., 2019).

Waterproofing technology is crucial for enhancing the resistance of concrete structures to water penetration, especially in regions like Nigeria with diverse climatic conditions. Waterproofing prevents the infiltration of water, which can

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cause structural deterioration, reinforcement corrosion, and reduced structural longevity (Okere et al., 2017). Historically, waterproofing concrete in Nigeria has depended on imported or expensive chemical admixtures. The prohibitive costs and limited availability of these materials have caused researchers and engineers to explore alternative, cost-effective, and sustainable solutions. This exploration has led to the investigation of local materials, specifically Rice Husk Ash (RHA) and Corn Cob, as promising options for enhancing concrete's waterproofing capabilities.

Waterproofing is a critical practice in construction, as it serves to protect structures from water infiltration, a threat that spans across geographical boundaries. In the context of a global project with Nigeria as a case study, it becomes evident that the challenges of waterproofing in concrete are not confined to one region but are shared by construction industries worldwide. One of the primary challenges that transcend borders is the variability in climate conditions. In Nigeria, where climatic zones range from arid to tropical, the waterproofing requirements can differ significantly. A similar situation is observed globally, from regions with excessive rainfall to those in arid desert environments, demanding adaptable solutions that cater to varying climate-related challenges.

In a paper published in 1991, Papadakis, Vayenas, and Fardis emphasized a concerning trend, stating, "Over the last two decades, there has been a disconcerting rise in instances of unsatisfactory durability observed in concrete structures, particularly those reinforced with steel." This issue of unsatisfactory durability is even more acute in India, where it has reached alarming levels. The worrisome situation in India, attributed to the early deterioration of reinforced concrete structures, is reflected in Technical Circular 1/99 from the Central Public Works Department, Government of India. This document notes that while structures dating back 50 years continue to provide reliable service, more recent constructions exhibit signs of distress within a mere couple of years after completion. Dr Anil (2015) points out that in the majority of concrete structures, the visible structural distress, such as cracks in concrete elements or even complete structural collapse, is an external manifestation of an underlying problem – corrosion in the ferrous components within the concrete. Several factors have contributed to this accelerated rate of structural distress in modern concrete structures. This acceleration began with the use of High Strength Deformed (HSD) reinforcing bars (rebars) in the construction of reinforced concrete structures, coupled with the use of deicing salts on highways in cold climates, predominantly in affluent countries. Furthermore, a significant factor in the corrosion process was the reduction in the period of wet curing for concrete, which decreased from 28 days to just 3–7 days, and in some instances, eliminated. Given the growing shift towards the utilization of Portland Pozzolan Cement (PPC) in place of Ordinary Portland Cement (OPC) in concrete, it is anticipated that this alteration in cement type will likely impact the durability of concrete structures unless specific measures are taken to address these concerns (Dr Anil, 2015). Ensuring the quality and effectiveness of waterproofing applications is another common challenge. The absence of rigorous quality control measures can lead to subpar waterproofing, putting structures at risk and necessitating costly repairs. Standardized quality assurance processes are imperative across the globe. Sustainability is a global concern, and the quest for environmentally friendly waterproofing solutions is a challenge shared by many regions. Achieving a balance between cost-effectiveness, durability, and eco-friendliness remains a complex task. The demand for sustainable construction practices is becoming increasingly pronounced. Maintenance and repair are challenges faced universally. Waterproofing isn't a one-time endeavour but requires continuous upkeep. Ensuring that building owners and maintenance personnel grasp the importance of proper maintenance is a challenge. Neglecting maintenance can lead to water related issues over time, emphasizing the necessity of education and awareness. Standards and regulations represent another common challenge. Adhering to waterproofing standards and regulations is crucial, especially in regions with lax enforcement. Nigeria, like many other areas, contends with inconsistent regulatory oversight that can lead to substandard practices. Globally, the need for comprehensive standards and effective regulation is a shared concern.

Waterproofing in the construction industry holds profound significance as it serves to ensure the long-term health, safety, and financial well-being of buildings and infrastructure. Beyond merely preventing water intrusion, it acts as a guardian of structural integrity, shielding against the destructive forces of water, such as corrosion and concrete decay. This preservation of structural health translates into cost savings, as it mitigates the need for extensive and expensive repairs down the line. Beyond economics, waterproofing is central to creating a safe and healthy environment by averting the growth of harmful moulds and safeguarding indoor air quality. Additionally, it bolsters energy efficiency, protecting insulation materials from moisture-related degradation. From a sustainability perspective, waterproofing contributes to resource conservation and waste reduction. It plays a pivotal role in adapting to the challenges posed by changing climates, particularly in regions like Nigeria, which experience diverse weather conditions. Its economic implications extend to job creation, while its scientific study propels advancements in construction materials. Furthermore, the dissemination of waterproofing knowledge fosters industry-wide improvement. In essence, waterproofing is an indispensable practice that underpins the integrity, resilience, and sustainability of constructions worldwide. Water seeping is a major problem in construction industries particularly when the buildings are constructed in a damped environment. A study by Mukesh and Singh in 2009 revealed that there are two ways for water to penetrate through the concrete. When concrete is under hydrostatic pressure on one surface, water passes through the channels formed by the interconnecting cracks and voids to the other surface. The other way for the passage of moisture through the concrete from the wet side to the dry side is by capillary action. Several compounds have been used as waterproofing admixtures. Certain admixtures can produce hydrophobic effects to repel water. Materials in this group reduce the passage of water through the dry concrete which would normally occur as a result of capillary action and not as a result of external water pressure. The waterrepelling admixtures alter the surface tension force of water to produce hydrophobic effects. There are certain pore-blocking admixtures which block the pores and capillaries in the concrete. However, there are some materials which are crystal-based and have both water-repelling and pore-blocking properties. These admixtures are very expensive but at the same time much superior to the other type. The enhancement of concrete durability often involves incorporating supplementary cementitious materials (SCMs), as noted by Belie, Soutsos, and Gruyaert (2018) and Munn, Chang, and Kao (2005). SCMs, with their pozzolanic activity and filling effect, contribute to high-performance concrete, showcasing improved mechanical properties and reduced permeability for enhanced durability (Hassan, Lachemi, & Hossain, 2012; Du & Liu, 2014; Mardani, Sezer, & Ramyar, 2014).

In reducing water penetration, specialized admixtures have been developed. According to ACI 212.3 R-16 (2016), Calvo et al. (2019), and Sideris et al. (2019), these admixtures are classified into two subcategories: Permeability-reducing admixture for nonhydrostatic conditions (PRAN) and permeability-reducing admixture for hydrostatic conditions (PRAH). Crystalline waterproofing admixtures (CWA), a type of PRAH, consist of Portland cement, treated quartz sand, and confidentially formulated "active chemicals" that enhance concrete density, block pores, and inhibit water penetration (Reiterman & Pazderka, 2016; Pazderka & Hájková, 2016). Research supports that CWA not only lowers water penetration but also promotes self-healing of cracks (Huang et al., 2019; Cuenca et al., 2021; Azarsa et al., 2020). Studies indicate variations in crack width for complete healing, ranging from 0.1 mm to 0.4 mm (Cuenca et al., 2021; Žáková et al., 2020; Azarsa et al., 2020; Huang et al., 2019). Notably, CWA is more effective in mixes with a higher water–binder ratio, supporting self-healing. Additionally, CWA improves resistance to freeze–thaw cycles, reduces chloride ion penetration (Al-Rashed & Jabari, 2020), enhances resistance to sulfate attack (Garcia et al., 2019), and does not significantly impact concrete compressive strength (Garcia et al., 2019; Cappellesso et al., 2016). The Nigerian construction industry, like many others around the world, is increasingly recognizing the importance of sustainable practices. Sustainable construction offers numerous benefits, including resource efficiency, reduced costs, improved public health, and environmental protection (Opoku & Ahmed, 2015). In Nigeria, the relevance of sustainable practices is underscored by the country's commitment to sustainable development goals and the necessity of addressing environmental challenges. The construction industry plays a pivotal role in achieving these goals, and the integration of sustainable practices is essential for reducing the environmental impact of construction projects and enhancing the industry's overall performance. Investigating the use of local materials for waterproofing in concrete aligns with this growing emphasis on sustainability in the Nigerian construction sector.

1.1. Rice husk ash (RHA)

Rice Husk Ash (RHA) is a byproduct of the rice milling industry, often considered waste. However, it has gained attention as a valuable material in construction, particularly as a pozzolan. Rice Husk Ash (RHA) possesses remarkable pozzolanic properties. This stems from its high silica content, which, when in contact with calcium hydroxide and water, reacts to form additional cementitious compounds within concrete. When incorporated into concrete, RHA enhances its durability, strength and impermeability, making it an attractive supplementary cementitious and waterproofing material. Investigating RHA's use as a waterproofing agent in concrete showcases its potential to transform an agricultural waste product into a resource for sustainable construction.

1.2. Corn cob ash (CCA)

Corn cobs, typically considered agricultural waste, have the potential to be repurposed as an eco-friendly aggregate in concrete. When properly processed, corn cobs can serve as a lightweight and porous aggregate or filler material (Amziane & Sonebi, 2022). Corn cobs exhibit inherent moisture-absorbing qualities, owing to their porous and lightweight nature. By absorbing moisture, corn cobs can help reduce the permeability of concrete, thereby reducing the risk of water ingress. Their low density and ability to absorb moisture make them a promising candidate for enhancing the porosity and water-resistant properties of concrete.

1.3. Application of RHA and CCA

RHA, a byproduct of rice milling, is rich in silica, making it an excellent pozzolan. When used as a partial replacement for cement, RHA improves the durability and strength of concrete while reducing its carbon footprint. Similarly, CCA, derived from corn cobs, contains a high percentage of silica and alumina. It acts as a supplementary cementitious material, contributing to the mechanical properties of concrete. Incorporating RHA and CCA in concrete not only utilizes agricultural waste but also offers an eco-friendly alternative to traditional cement, promoting resource efficiency and environmental conservation in the construction industry.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement is employed as a control reference to compare the waterproofing abilities of RHA and Corn Cob. The OPC used was produced in Nigeria by Dangote Cement Company, grade 42.5 and is in compliance with CEM II of NIS-444 Part 1 (NIS-444,2003).

2.1.2. Fine aggregates

River sand from the banks of the Otamiri River was used as fine aggregates. It was clean, sharp, and free from contaminants such as clay, loam, and dirt. The fine aggregates had a coefficient of uniformity of 2.7, indicating they were well-graded according to the standards set by BS 812-2:1995.

2.1.3. Coarse aggregates

The coarse aggregates were obtained from local retailers and were free of dirt. Crushed granite with a maximum nominal size of 25mm and a specific gravity of 2.72 was used as coarse aggregate, in accordance with BS 812-2:1995.

2.2. Methods

2.2.1. Sieve analysis test

The sieve analysis test was used to get the particle size distribution curve of the fine and coarse aggregates. The test was done following BS 1372:1990.

2.2.2. Specific gravity test

The pycnometer test was used. Two pycnometers with weights of 753 grams and 137 grams were used to determine the specific gravity of the fine aggregates and coarse aggregates respectively.

The test was conducted following the recommendations of BS 812-2:1995.

2.2.3. Mix proportion

For the preparation of concrete specimens, a water-cement ratio of 0.6 was maintained. The mix ratio used was 1:2:4, consisting of one part cement, two parts fine aggregate (such as sand), and four parts coarse aggregate (such as gravel). This ratio was consistent for all the concrete specimens. Each concrete cube was cast with dimensions of 150mm × 150mm × 150mm. The inclusion of corn cob ash (CCA) and rice husk ash (RHA) in the concrete mix was determined by the specific amount of water sealant powder required for each batch. This proportion ensured that the concrete mix was consistent with the experimental design and that the additives were incorporated correctly to evaluate their effects on the concrete's properties

2.2.4. Slump test

The apparatus used for the slump test were the slump cone, the tamping rod, and the measuring ruler. Slump test was carried out on fresh concrete with the following as additives; 40%RHA - 60%CCA, 50%RHA - 50%CCA, 60%RHA – 40%CCA, all in accordance with (BS1881-102,1993).

2.2.5. Waterproofing absorption test

The water absorption test was conducted by weighing the concrete specimens before and after curing. A total of 60 cubes were cast for this purpose. The table below provides a detailed presentation of the results obtained from this test.

3. Result and Discussion

3.1. Slump Test

The slump test results provide details of the workability of the concrete specimens containing different proportions of Rice Husk Ash (RHA) and Corn Cob Ash (CCA), alongside the control group.

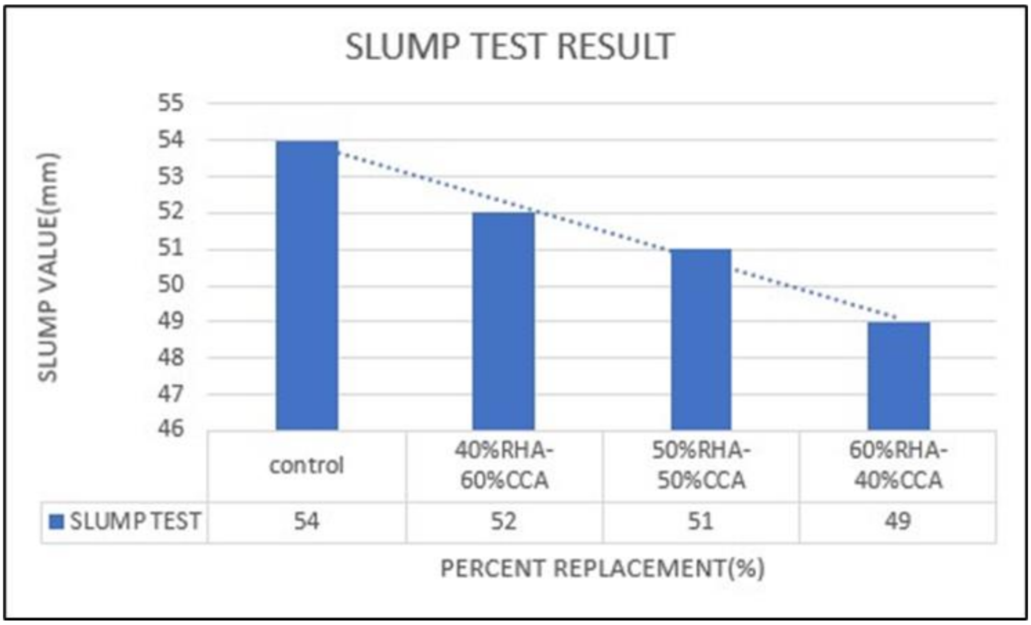

Figure 1 Slump test result summary

The control group exhibited a slump value of 54mm, indicating good workability and flowability of the concrete mix with the prescribed water-cement ratio of 0.6 and mix ratio of 1:2:4. As the proportion of RHA increased in the concrete mixtures, there was a slight reduction in slump values. The specimens containing 40% RHA - 60% CCA, 50% RHA - 50% CCA, and 60% RHA- 40% CCA exhibited slump values of 52mm, 51mm, and 49mm, respectively. This reduction in slump values with higher proportions of RHA suggests a slight decrease in workability, which could be attributed to the pozzolanic properties of RHA. Pozzolanic materials tend to absorb water from the concrete mix, resulting in a stiffer consistency and reduced flowability. Despite the slight decrease in slump values, the observed slump values for all specimens remained within an acceptable range for concrete workability, indicating that the incorporation of RHA and CCA did not significantly compromise the overall workability of the concrete mixtures.

3.2. Water Absorption Test

The water absorption rate of all the specimen are shown in the table below.

Table 1 Water absorption test result

WEIGHT OF CONCRETE CUBE (150mm x 150mm x 150mm) BEFORE AND AFTER CURING																					
SPECIMEN		**7 DAYS (KG)**			**AVERAGE (KG)**	**WATER RETAINED**	**14 DAYS (KG)**			**AVERAGE (KG)**	**WATER RETAINED**	**21 DAYS (KG)**			**AVERAGE (KG)**	**WATER RETAINED**	**28 DAYS (KG)**			**AVERAGE (KG)**	**WATER RETAINED**
CONTROL	Before Curing	8.20	8.40	8.10	**8.23**	**0.37**	8.10	8.10	8.30	**8.17**	**0.40**	8.10	8.20	8.10	**8.13**	**0.60**	8.50	8.20	8.20	**8.30**	**0.65**
	After Curing	8.60	8.70	8.50	**8.60**		8.50	8.40	8.80	**8.57**		8.60	8.80	8.70	**8.70**		9.10	8.90	8.85	**8.95**	
WATER SEALANT	Before Curing	8.30	8.10	8.50	**8.30**	**0.08**	8.10	8.40	8.20	**8.23**	**0.02**	8.20	8.20	8.40	**8.27**	**0.30**	8.30	8.10	8.10	**8.17**	**0.33**
	After Curing	8.40	8.20	8.55	**8.38**		8.10	8.40	8.25	**8.25**		8.40	8.30	8.70	**8.47**		8.60	8.40	8.50	**8.50**	
RHA-CCA (60%-40%)	Before Curing	8.30	8.30	8.10	**8.23**	**0.17**	8.20	8.50	8.20	**8.30**	**0.13**	8.30	8.10	8.20	**8.20**	**0.10**	8.20	8.10	8.20	**8.17**	**0.07**
	After Curing	8.50	8.40	8.30	**8.40**		8.30	8.70	8.30	**8.43**		8.40	8.10	8.30	**8.27**		8.30	8.20	8.20	**8.23**	
RHA-CCA (50%-50%)	Before Curing	8.10	8.50	8.20	**8.27**	**0.33**	8.30	8.40	8.20	**8.30**	**0.33**	8.10	8.10	8.30	**8.17**	**0.40**	8.40	8.30	8.10	**8.27**	**0.30**
	After Curing	8.40	8.90	8.50	**8.60**		8.60	8.70	8.60	**8.63**		8.40	8.40	8.70	**8.50**		8.70	8.60	8.40	**8.57**	
RHA-CCA (40%-60%0	Before Curing	8.40	8.10	8.10	**8.20**	**0.07**	8.30	8.30	8.20	**8.27**	**0.03**	8.10	8.50	8.10	**8.23**	**0.10**	8.20	8.20	8.10	**8.17**	**0.00**
	After Curing	8.50	8.20	8.10	**8.27**		8.30	8.40	8.20	**8.30**		8.20	8.55	8.20	**8.32**		8.20	8.20	8.10	**8.17**	

The water absorption test results illustrated above, provide details about the moisture resistance of the concrete specimens containing different proportions of Rice Husk Ash (RHA) and Corn Cob Ash (CCA), compared to the control and water sealant specimens. The control group exhibited a gradual increase in water absorption over the curing period, with water retention values of 0.37 kg, 0.40 kg, 0.60 kg, and 0.65 kg after 7 days, 14 days, 21 days, and 28 days of curing, respectively. This increase in water retention highlights the susceptibility of conventional concrete to moisture penetration over time. In contrast, the water sealant specimen demonstrated significantly lower water absorption rates, with minimal water retention values of 0.08 kg, 0.02 kg, 0.30 kg, and 0.33 kg across the same curing periods. This underscores the effectiveness of chemical waterproofing agents in mitigating moisture ingress and enhancing the waterproofing properties of concrete. Graphical presentation of the result is shown below.

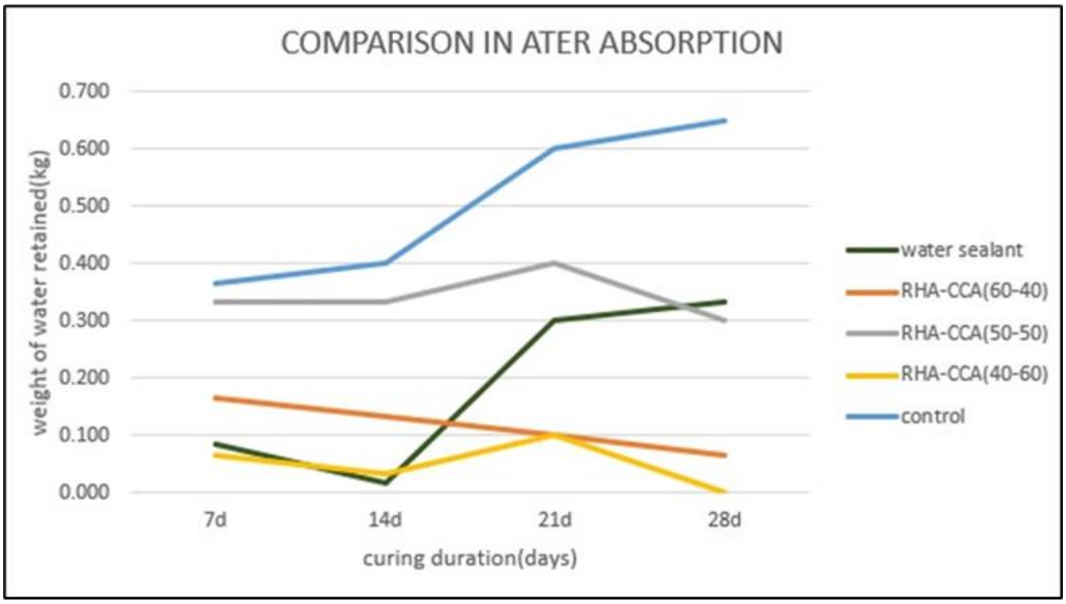

Figure 2 Graphical representation, comparing the water absorption properties of all specimen

The specimens incorporating RHA and CCA displayed varying degrees of water absorption reduction compared to the control group. Notably, the 60% RHA - 40% CCA mixture exhibited the lowest water retention values throughout the curing period, with a final water retention of 0.07 kg after 28 days. This suggests that the incorporation of RHA and CCA can effectively mitigate moisture absorption in concrete, particularly at higher proportions.

Interestingly, the 40% RHA - 60% CCA mixture demonstrated a complete absence of water retention after 28 days of curing, indicating exceptional moisture resistance. This highlights the potential synergistic effect of combining RHA and CCA in concrete mixtures to achieve superior waterproofing properties. In conclusion, the water absorption test results show the effectiveness of incorporating RHA and CCA as sustainable alternatives for enhancing the moisture resistance of concrete.

4. Conclusion

Based on the findings from the slump test results and water absorption test results, it can be concluded that the incorporation of Rice Husk Ash (RHA) and Corn Cob Ash (CCA) as additives in concrete mixtures effectively enhances both the workability and waterproofing properties of the concrete. The slump test results indicated that while there was a slight decrease in workability with higher proportions of RHA, all specimens maintained acceptable slump values within the range suitable for concrete construction. This suggests that the addition of RHA and CCA did not compromise the overall workability of the concrete mixtures. Furthermore, the water absorption test results revealed that concrete specimens containing RHA and CCA exhibited significantly lower water retention values compared to the control group. Among the different proportions tested, the 40% RHA - 60% CCA mixture demonstrated exceptional moisture resistance, with complete absence of water retention after 28 days of curing. This indicates that the combination of 40% RHA and 60% CCA is most suitable for achieving optimal waterproofing properties in concrete.

In conclusion, based on the combined analysis of slump test and water absorption test results, the 40% RHA - 60% CCA additive proportion emerges as the most suitable choice for enhancing both workability and waterproofing performance of concrete mixtures. This proportion offers a balanced approach to improving concrete durability while minimizing material costs and environmental impact.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

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