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Sustainable Approach of Enhancing Concrete Performance Using Palm Bunch Ash

Akumefula Moses Iheanyichukwu[1], Chikwe Ikechukwu Sampson[2], Eziukwu Charles Chidi[3], Chikwe Oluchukwu Benedicta[4]

[1,2,3]Chemistry/Biochemistry Department, Imo State Polytechnic, Omuma, Oru-East, Imo State.
[4]Chemistry Department, Nnamdi Azikiwe University, Awka, Anambra State.

(*) Corresponding author: Akumefulamoses066@gmail.com; 08036718632

Abstract

This study investigates the sustainable utilization of Palm Bunch Ash (PBA) as a partial replacement for cement in concrete to enhance its performance while promoting eco-friendly construction practices. Various concrete mixes were prepared with PBA replacement levels of 0%, 10%, 20%, and 30%, and their compressive strengths were evaluated at curing ages of 7, 14, 21, 28, 60, and 90 days. The results demonstrate that while the control mix (0% PBA) exhibited the highest early-age strength, mixes containing PBA showed progressive strength gains over time, with the 10% replacement mix (A1) achieving comparable or slightly higher strength than the control after 60 and 90 days. Higher PBA contents (20% and 30%) resulted in lower early strength but displayed promising strength development at later ages. These findings highlight the potential of PBA as a sustainable supplementary cementitious material that can improve long-term concrete performance while reducing reliance on traditional cement, thereby lowering carbon emissions and contributing to environmental conservation in the construction industry.

Keywords: Cement replacement, compressive strength, concrete production, durability, Palm bunch ash, workability

Introduction

The need to maintain a sustainable environment and preserve the future has become increasingly important. The cement industry, in particular, has a significant impact on the environment, with the production of 251.2 million tonnes of cement per year [1].The use of coal-based thermal power plants, which generate huge amounts of fly ash (FA), has also become a major concern. Research has shown that the use of classified FA can improve the compressive strength of blended cement paste [2]. However, the original FA is still largely used by the cement industry in the manufacture of Portland pozzolana cement (PPC). There is still a significant scope for the use of FA by partially replacing cement in concrete and mortars. Pozzolans are natural or artificial materials that contain silica and alumina or ferruginous materials in a reactive form. They are commonly used as additives to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete [3]. There

are various types of pozzolans, including Portland pozzolana, lime pozzolana, and clay pozzolana. However, there are many other pozzolans of volcanic origin, such as volcanic ash, tuffs, and other diatomaceous earths, as well as agricultural wastes [4][5][6]. The use of pozzolans dates back to ancient times, with the early Egyptians, Greeks, and Romans using volcanic tuff and other materials to construct buildings and structures [7].

Concrete is the most widely used man-made material in the world, with nearly 2.6 billion tonnes of Portland and hydraulic cement produced worldwide in 2008 [8]. However, the production of cement generates significant amounts of carbon dioxide emissions, with approximately one ton of CO_2 released in the production of one ton of Portland cement.

The use of palm bunch ash (PBA) as a partial replacement for cement in concrete production has gained attention in recent years due to its potential benefits, including reducing the cost of concrete production, reducing the environmental impact of concrete production, and improving the durability of concrete. However, there is limited research on the compressive strength and workability of concrete with PBA as a partial replacement for cement [9].

This study aims to investigate the compressive strength and workability of concrete with PBA as a partial replacement for cement.

Materials and Method

The cement used was ordinary portland cement of strength class 32.5R. The cement conformed to [10].The pozzolana used is of ASTM Type N. Crushed granite of nominal size 20mm used in producing concrete. The water used in mixing looked clean and free from any visible impurities. It conformed to the requirements of [11]. Natural river sand with a specific gravity of 2.53 and a bulk density of 1550kgm-3 was used. Six different mixes were used for the study. A control mix of ratio 1:2:4 batched by mass using a water-binder ratio of 0.55. The control mix was produced using OPC only as binder while in other mixes, pozzolana was used to replace 10%, 20%, 30%, 40% and 50% of the mass of ordinary cement in the control mix.

Results and Discussion

The results of the particle size analysis, slump test, and compressive strength test are presented in Tables 1-3.

Table 1: Particle Size Analysis of Fine Aggregate

Sieve sizes (mm)	Mass of sample retained (g)	Mass of sample passing (g)	Percentage retained (%)	Percentage passed (%)	Cumulative Percentage retained (%)
5.0	0.00	500	0.00	100.00	0.00
2.36	91.60	408.40	18.32	81.68	88.32
1.18	49.80	358.60	9.96	71.72	28.28
600	172.10	186.50	34.42	37.30	62.70
300	122.50	64.00	24.50	12.80	87.70
150	35.80	28.20	7.16	5.64	94.36
pan	28.20	0.00	5.64	0.00	100.00

Table 2: Slump Test Results

Mix	Height of cone (mm)	Height of slump concrete (mm)	Slump value (mm)
Control	300	235	65
10% replacement	300	230	70
20% replacement	300	232	68
30% replacement	300	234	69

Table 3: Compressive Strength Test Results

Mix Nos	**PBA Control(%)**	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**60 Days**	**90 Days**
C	0	19.88	21.98	24.89	26.71	27.56	28.00
A1	10	14.22	17.78	20.44	22.00	27.66	28.55
A2	20	12.89	16.89	18.18	21.07	26.88	28.22
A3	30	11.02	16.89	18.18	19.56	24.89	27.33

Discussion of Results

The results show that the workability and compressive strength of the concrete decrease as the percentage of PBA increases. The control mix (0% PBA) had the highest compressive strength at all ages, while the mix with 30% PBA had the lowest compressive strength [12].

The decrease in workability and compressive strength with increasing PBA (Palm Boiler Ash) content can be attributed to the fact that PBA has a higher water absorption capacity than cement. This increased absorption reduces the free water available for hydration, which in turn decreases the strength of the concrete. Similar findings have been reported by [13] [14] and [15] who noted that the high porosity and surface area of PBA absorb more mixing water, thereby reducing the water-to-cement ratio and adversely affecting workability and compressive strength. Furthermore, the lower density of PBA compared to cement contributes to a reduction in the overall density of the concrete, which can also negatively impact its mechanical properties. These observations are consistent with the study by who found that using agricultural ashes as cement replacements generally reduces concrete density and compressive strength at higher replacement levels.

However, despite these drawbacks, the use of PBA as a partial replacement for cement has several advantages. It can reduce the cost of concrete production, mitigate the environmental footprint associated with cement manufacturing, and, under certain conditions, enhance concrete durability. For instance, studies by [16] and [15] have shown that when used in optimal amounts, PBA can improve long-term durability characteristics, such as resistance to chloride penetration and sulfate attack, due to its pozzolanic activity. This dual nature—performance trade-off versus environmental and economic benefits—highlights the importance of determining the optimal replacement level of PBA. Researchers generally agree that replacing cement with up to 10–15% PBA by weight yields the most balanced results in terms of mechanical strength and durability[14nb][18][19].

Conclusion

This study investigated the compressive strength and workability of concrete with palm bunch ash (PBA) as a partial replacement for cement. The results show that the workability and compressive strength of the concrete decrease as the percentage of PBA increases. However, the use of PBA as a partial replacement for cement can have benefits such as reducing the cost of concrete production, reducing the environmental impact of concrete production, and improving the durability of concrete. The optimal percentage of PBA replacement for cement needs to be determined, taking into account the benefits and drawbacks of using PBA as a partial replacement for cement. The Replacement of cement with pozzolana

significantly increased the strength of concrete Replacement of 30% of the mass of cement with pozzolana achieved the maximum value of compressive. The results show that the workability and compressive strength of the concrete decrease as the percentage of PBA increases. The control mix (0% PBA) had the highest compressive strength at all ages, while the mix with 30% PBA had the lowest compressive strength.

Recommendations

1. Further research is needed to determine the optimal percentage of PBA replacement for cement in concrete production.
2. The use of PBA as a partial replacement for cement should be considered in conjunction with other supplementary cementitious materials to improve the durability and sustainability of concrete.
3. The environmental impact of using PBA as a partial replacement for cement should be assessed and compared to traditional concrete production methods.

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