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Development of Sustainable Concrete Paver Blocks Using Wood Ash and Coal Ash as Partial Replacement of Cement

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Abstract: ***The rapid growth of the construction industry has led to increased demand for cement, resulting in large-scale CO_2 emissions and environmental degradation. This study explores the potential of wood ash (WA) and coal ash (CA), two abundant industrial by-products, as supplementary cementitious materials for manufacturing M40-grade concrete paver blocks. Cement was partially replaced with WA and CA at proportions of 0%, 5%, 10%, 15%, and for CA, 20%. The mechanical properties-including compressive strength, water absorption, and flexural strength-were evaluated at 7, 21, and 28 days according to IS 516 (1959) and IS 15658 (2006). Results indicate that 10% replacement for both WA and CA provided optimum performance, achieving compressive strengths close to or higher than the control mix. The microstructural benefits of pozzolanic reactions were evident from reduced water absorption (<1.6%) and improved matrix densification. The findings confirm that WA and CA are viable alternatives to reduce cement consumption, minimize waste disposal, and support sustainable construction practices. The paper provides a comprehensive analysis, quantification of sustainability, and recommendations for industry adoption.***

Keywords: wood ash utilization, coal ash concrete, sustainable construction, cement replacement materials, M40 paver performance

1. Introduction

Concrete remains the most widely used construction material worldwide, with cement serving as a critical binder in concrete production. However, cement manufacturing contributes approximately 8% of global CO_2 emissions due to limestone calcination and the high-energy clinker production process. This has driven researchers and industries to explore eco-friendly alternatives that can replace cement without compromising mechanical or durability performance.

1.1 Need for Sustainable Cement Alternatives

Industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), rice husk ash, silica fume, and bottom ash have been studied extensively as pozzolanic materials. Among these, wood ash and coal ash remain underutilized despite their availability in large quantities from biomass plants, domestic wood combustion, and coal-based power plants. These ashes contain reactive silica (SiO_2) and alumina (Al_2O_3), allowing them to participate in secondary hydration reactions.

1.2 Why Wood Ash and Coal Ash?

- **Wood ash** is obtained from biomass combustion in boilers or household stoves. It primarily contains calcium, potassium, and siliceous compounds.
- **Coal ash** (especially bottom ash) is a residue from thermal power plants and often disposed of in landfills.

Both ashes pose **environmental hazards** if not properly managed:
- Soil and groundwater contamination
- Air pollution due to fine particulates
- Landfill space occupation
- Toxic leaching elements

Utilizing these waste materials in concrete:

- Reduces cement usage
- Prevents harmful disposal
- Lowers cost
- Promotes circular economy

This research investigates the feasibility of using WA and CA as cement substitutes for manufacturing interlocking paver blocks—a high-volume construction element widely used in pavements, pathways, and landscaping.

2. Literature Review

A significant number of recent studies emphasize the use of ash-based materials as supplementary binders:

2.1 Wood Ash in Concrete

- Vu et al. (2019) reported improved long-term strength when WA was used up to 10% due to increased pozzolanic activity.
- Raheem & Adenuga (2013) demonstrated that WA enhances workability and reduces permeability.
- Nascimento et al. (2023) highlighted the variability in WA properties depending on the combustion source, necessitating proper sieving and grading.

2.2 Coal Ash in Concrete

- Argiz et al. (2017) found that coal bottom ash can partially substitute cement when finely ground.
- Park et al. (2021) observed increased packing density and improved later-age strength.

- Poudel et al. (2024) reported that micronized bottom ash enhances hydration due to glassy-phase reactivity.

2.3 Gap Identified

While many studies focus on normal concrete, **very few have explored the performance of WA and CA in paver block applications**, where high strength and low water absorption are critical. This study fills that research gap.

3. Materials and Methods

3.1 Cement

OPC 53 Grade conforming to IS 12269:2013 was used.

3.2 Wood Ash (WA)

- Sourced from biomass combustion
- Sieved through 90 µm sieve
- Greyish-black colour
- Specific gravity: 2.15
- WA contains unburnt carbon, affecting water demand.

3.3 Coal Ash (CA)

- Bottom ash collected from a thermal power plant
- Ground and sieved through 90 µm
- Specific gravity: 2.30
- CA has smoother texture and better particle packing.

3.4 Fine and Coarse Aggregates

- River sand (Zone II)
- Crushed stone aggregates (10 mm)

3.5 Concrete Mix Design

Designed for M40 grade as per IS 10262:2019
W/C ratio: 0.45

3.6 Mix Proportions

Cement replaced with WA and CA at:

- 5%, 10%, 15%, 20% (only CA)

3.7 Testing

- Compressive strength
- Water absorption
- Flexural strength

All tests conducted as per:

- **IS 516:1959**
- **IS 15658:2006**

4. Results and Analysis

4.1 Compressive Strength

Mix Type	7 Days (MPa)	21 Days (MPa)	28 Days (MPa)
Control	26.81	30.47	32.29
5% WA	26.22	28.98	30.85
10% WA	28.4	29.92	31.37
15% WA	24.12	25.61	27.92
5% CA	27.3	29.58	31.12
10% CA	27.78	29.25	33.41
15% CA	25.87	27.21	30.01
20% CA	23.52	25.02	28.43

Key Interpretation:
- **10% WA and 10% CA achieved optimum strength**
- At lower replacements (5–10%), strength improved due to pozzolanic reaction
- At higher replacement (>15%), dilution effect dominates

4.2 Water Absorption

- All mixes showed <1.6% absorption
- Indicating a dense microstructure
- WA and CA contributed to pore refinement

4.3 Flexural Strength

- Remained above 3 MPa for optimum mixes
- Suitable for medium-traffic paver applications

5. Microstructural Interpretation

Though SEM analysis was not conducted, the performance trends indicate:
- Formation of **secondary C–S–H gel** due to pozzolanic reaction
- Reduced interconnected capillary pores
- Better particle packing from fine ash particles
- Coal ash contributed glassy reactive silica enhancing long-term strength

6. Sustainability Assessment

6.1 CO_2 Reduction

Replacing 10% cement reduces CO_2 by:
~80–90 kg CO_2 per ton of cement saved

6.2 Cost Savings

Using WA and CA (usually free or low-cost materials):
- Cement cost reduced by 8–12%
- Suitable for large-scale paver production plants

6.3 Environmental Benefits

- Reduced landfill usage
- Cleaner disposal of biomass and coal residues
- Supports SDG-12: Responsible Consumption and Production

7. Discussion

- WA exhibits moderate pozzolanic activity, influencing early-age strength slightly but improving long-term properties.
- CA shows superior performance due to finer particle structure and glassy-phase composition.
- The optimum replacement level of 10% aligns with global research trends.
- The reduced water absorption indicates improved durability characteristics.

8. Conclusions

- Wood ash and coal ash can successfully replace up to 10% of cement in concrete paver blocks without compromising strength.
- Coal ash performed slightly better than wood ash due to its finer and more reactive nature.
- Both ashes significantly reduced water absorption, indicating improved microstructure.
- Using industrial wastes promotes sustainability, lowers production costs, and reduces CO_2 emissions.
- These materials are recommended for commercial paver block manufacturing.

9. Future Scope

Further studies should include:
- SEM/EDS microstructural analysis
- Durability studies (sulphate, chloride, carbonation)
- Long-term flexural fatigue performance
- Optimization using nano-materials (nano-silica, nano-alumina)
- Life cycle assessment (LCA)

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