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Original Article

Experimental Study on Cement Brick Using Low-Density Polyethylene (LDPE) Plastics and Biochar

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ABSTRACT

The construction industry's high demand for conventional materials like cement and sand poses significant environmental challenges, including high CO_2 emissions and natural resource depletion. Concurrently, the management of non-biodegradable plastic waste (LDPE) and agricultural biomass remains a critical issue. This study investigates the feasibility of producing sustainable cement bricks by partially replacing cement with biochar (10%, 20%, 30%) and sand with shredded LDPE plastic waste (5%, 10%, 15%). Three prototype bricks were developed and subjected to comprehensive tests for compressive strength, water absorption, efflorescence, hardness, and flammability. Results indicate that Prototype Brick 1 (10% biochar, 5% LDPE) achieved the highest compressive strength of 7 MPa at 28 days, comparable to first-class clay bricks, while exhibiting balanced properties in water absorption (11%) and low flammability. Although higher replacement levels reduced mechanical strength, all prototypes remained suitable for non-structural applications. This research demonstrates a viable pathway for waste valorization, reducing the carbon footprint of construction materials and promoting a circular economy in the building sector.

Keywords: LDPE Plastic Waste, Biochar, Sustainable Construction, Cement Brick, Waste Valorization, Circular Economy

INTRODUCTION

Concrete bricks are fundamental building blocks in global construction, but their production relies heavily on cement and sand, materials associated with substantial carbon emissions and environmental degradation. The cement industry alone contributes approximately 8% of global anthropogenic CO_2 emissions. Furthermore, the extensive extraction of natural sand leads to ecological imbalance and resource scarcity. In parallel, the accumulation of plastic waste, particularly Low-Density Polyethylene (LDPE) from packaging materials, presents a severe environmental threat due to its non-biodegradable nature. Similarly, agricultural waste often ends up in landfills or is burned openly, contributing to air pollution. Integrating these waste streams into construction materials offers a promising dual solution: diverting waste from landfills and reducing the consumption of virgin resources. Biochar, a carbon-rich solid produced from the pyrolysis of biomass, can act as a supplementary cementitious material and a carbon sink. LDPE plastic, when shredded, can replace a portion of fine aggregates, introducing properties like reduced density and enhanced toughness. This study explores the synergistic use of these two waste materials in cement brick production, evaluating their impact on the brick's key engineering properties to determine optimal mix proportions for sustainable construction.

LITERATURE REVIEW

The pursuit of sustainable alternatives in construction has led to significant research on incorporating industrial and domestic waste into concrete and masonry products. **Rahman et al. (2020)** investigated the use of LDPE as a sand replacement (5–15%), finding that 5–10% replacement improved toughness and impact resistance, though compressive strength decreased beyond 10% due to weak bonding with the cement matrix. **Frigione (2010)** emphasized that

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

LDPE inclusion reduces concrete's unit weight and enhances its thermal insulation capacity. **Ismail & Al-Hashmi (2008)** highlighted enhanced ductility but also noted increased porosity with higher plastic content. On the use of biochar, **Gupta et al. (2021)** demonstrated that replacing cement with 5–10% biochar improved compressive strength and water retention due to its fine particle size and internal curing ability. **Tan et al. (2018)** reported improved thermal insulation and moisture regulation in biochar-modified concrete. **Lehmann & Joseph (2015)** detailed the carbon sequestration potential of biochar, which can significantly lower the embodied carbon of construction materials. The combined use of LDPE and biochar is a novel approach. **Ahmed et al. (2019)** proposed that blending plastic and biochar could yield composites with improved thermal properties and durability. **Ramesh & Kumar (2021)** produced eco-bricks using 10% biochar and 5% LDPE, reporting compressive strengths close to traditional clay bricks and suggesting a complementary relationship where biochar mitigates the weaknesses introduced by LDPE. This study builds upon these findings by systematically evaluating a range of replacement values for both LDPE and biochar in cement bricks, providing a comprehensive analysis of their combined effect on structural and durability properties.

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MATERIALS AND METHODS

MATERIALS

The materials used in this experimental investigation were sourced locally to emphasize practicality and are listed in Table 1.

Table 1: Materials and their specifications.

Material	Specification	Source
Cement	Portland Pozzolana Cement (PPC), 43-Grade, IS 1489(Part 1)	Local supplier, Jorhat
Fine Aggregate	Natural river sand, conforming to IS 383:1970 Zone-II	CSIR-NEIST Campus, Jorhat
LDPE Plastic	Post-consumer packaging films and bags	GEC & CSIR-NEIST Campus
Biochar	Pyrolyzed (300–600°C) sugarcane bagasse, vegetable waste, nutshells (sieved to <2.36 mm)	GEC Campus & Golaghat Town
Water	Potable water, free from impurities	CSIR-NEIST Campus

The success of integrating waste materials into construction elements hinges on the careful selection and preparation of constituents. The following materials were meticulously sourced and processed for this study:

1. **Cement:** Ordinary Portland Cement (OPC) of 43-grade, conforming to IS 8112:1989, was used as the primary binding agent for its consistent quality and widespread availability.

2. **Fine Aggregate:** Naturally available river sand, confirming to Grading Zone-II as per IS 383:1970, was used. The sand was air-dried to remove surface moisture, which could alter the water-cement ratio, and then sieved to remove any oversized particles or organic matter.

3. **LDPE Plastic Waste:** Post-consumer LDPE waste, primarily from packaging films and bags, was collected from college and institutional campuses. The collected plastic was thoroughly cleaned with water to remove dirt and adhesives, air-dried, and then mechanically shredded into small, irregular flakes ranging from 3–10 mm in size to facilitate mixing and interlocking within the cement matrix.

4. **Biochar:** Biochar was produced locally using a controlled pyrolysis process. A mixture of common agricultural residues—sugarcane bagasse, mixed vegetable waste, and nutshells—was carbonized in a low-oxygen environment at temperatures between 300–600°C. The resulting biochar was then crushed and sieved through a

2.36 mm IS sieve to achieve a fine, consistent particle size comparable to cement, ensuring it could act as a effective filler and partial cement replacement.

5. **Water:** Potable water, free from impurities, acids, and alkalis that could interfere with the hydration process of cement, was used throughout the mixing process.

- **Biochar Preparation**

- **LDPE Preparation**

Mix Proportions and Brick Preparation

A standard brick size of 220 mm × 100 mm × 70 mm was adopted. A control mix with a cement-to-sand ratio of 1:6 by weight was established as the baseline. The water-cement ratio was maintained at 0.50 for all mixes to ensure workability. Three distinct prototype mixes were designed by progressively replacing cement with biochar and sand with LDPE plastic, as detailed in Table 1.

Table 1: Mix Proportions for Prototype Bricks (Quantities per Brick)

Material	Prototype 1	Prototype 2	Prototype 3
Cement (kg)	0.459	0.408	0.357
Sand (kg)	3.23	3.06	2.89
LDPE (kg)	0.17	0.34	0.51
Biochar (kg)	0.051	0.102	0.153
Water (litres)	0.23	0.20	0.18
% Replacement	10%C, 5%S	20%C, 10%S	30%C, 15%S
Note: C = Cement replacement by Biochar, S = Sand replacement by LDPE.			

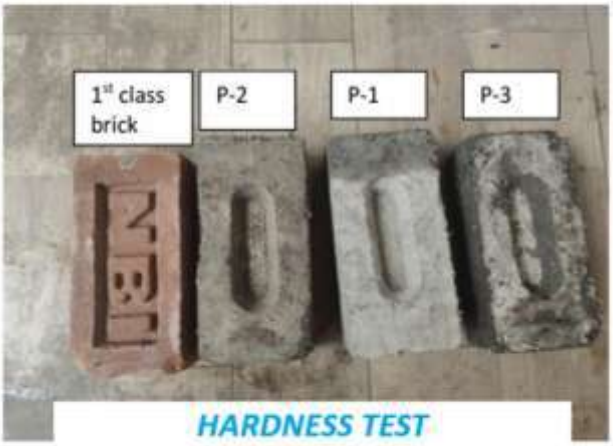
The dry materials (cement, sand, biochar, LDPE) were first mixed manually to achieve a homogeneous blend. Water was then added gradually, and mixing continued until a uniform, semi-dry consistency was attained, suitable for brick pressing. The bricks were cast using a manual brick press machine to ensure consistent density and shape. They were demolded carefully after initial setting and transferred to a curing tank, where they were water-cured for 28 days to achieve maximum strength before testing

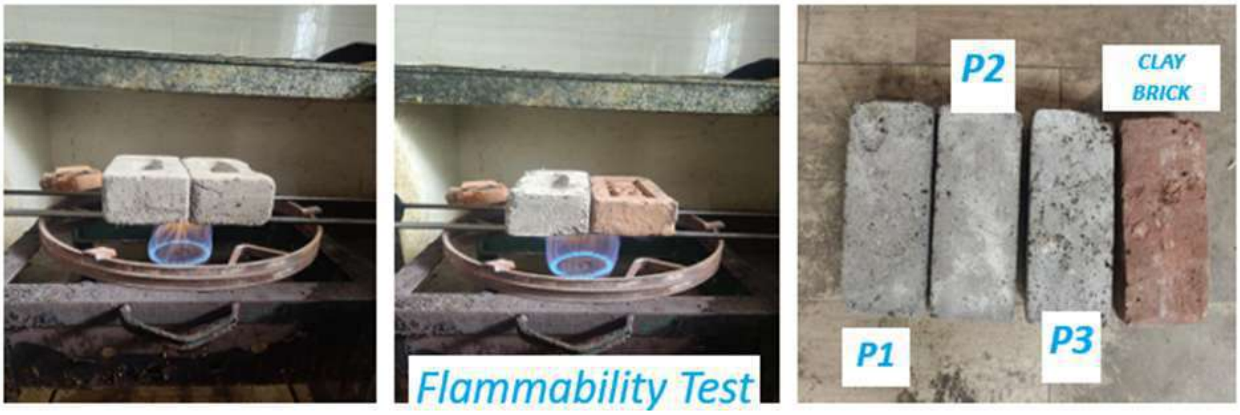
- **Brick Preparation**

Testing Methods

The cured brick specimens were subjected to a battery of tests following relevant Indian Standard (IS) codes to evaluate their engineering and durability properties:

1. **Compressive Strength Test (IS 3495-Part 1):** This key test was performed on a Compression Testing Machine (CTM) at 7 and 28 days of curing. The load was applied axially and gradually until failure, and the ultimate load was recorded to calculate compressive strength.
2. **Water Absorption Test (IS 3495-Part 2):** Bricks were dried in an oven at 105–115°C to a constant weight, then immersed in clean water for 24 hours. The percentage of water absorbed was calculated from the difference in wet and dry weights, indicating porosity and durability.
3. **Efflorescence Test (IS 3495-Part 3):** Brick specimens were placed in a shallow dish with water for 24 hours, allowing water to be absorbed by capillary action. After the water was fully absorbed, the bricks were inspected for the presence and severity of white salt deposits on the surface.
4. **Hardness Test:** A simple but effective field test was conducted by scratching the surface of the brick with a hard, sharp object. The resistance to scratching provided a qualitative measure of surface hardness and abrasion resistance.
5. **Flammability Test:** A direct flame from a butane torch was applied to the brick surface for 2-5 minutes. The brick's reaction to fire, including melting, charring, smoke emission, and sustained burning, was observed to assess its fire risk





RESULTS AND DISCUSSION

The results from the comprehensive testing of the three prototypes are summarized in Table 2 and discussed in detail below. For context, the properties of a standard first-class clay brick are provided for comparison.

Table: Summary of Test Results for Prototype and Clay Bricks

Property	Proto 1	Proto 2	Proto 3	Clay Brick
Comp. Strength @7d (MPa)	4.0	3.0	3.0	--
Comp. Strength @28d (MPa)	7.0	7.0	6.0	12.0
Water Absorption (%)	11.0	13.5	16.0	18.0
Efflorescence	Nil-Slight	Slight	Moderate	Slight-Mod
Hardness	Hard	Med. Hard	Soft-Med	Med. Hard
Flammability	Low	Moderate	Mod-High	Non-Flammable

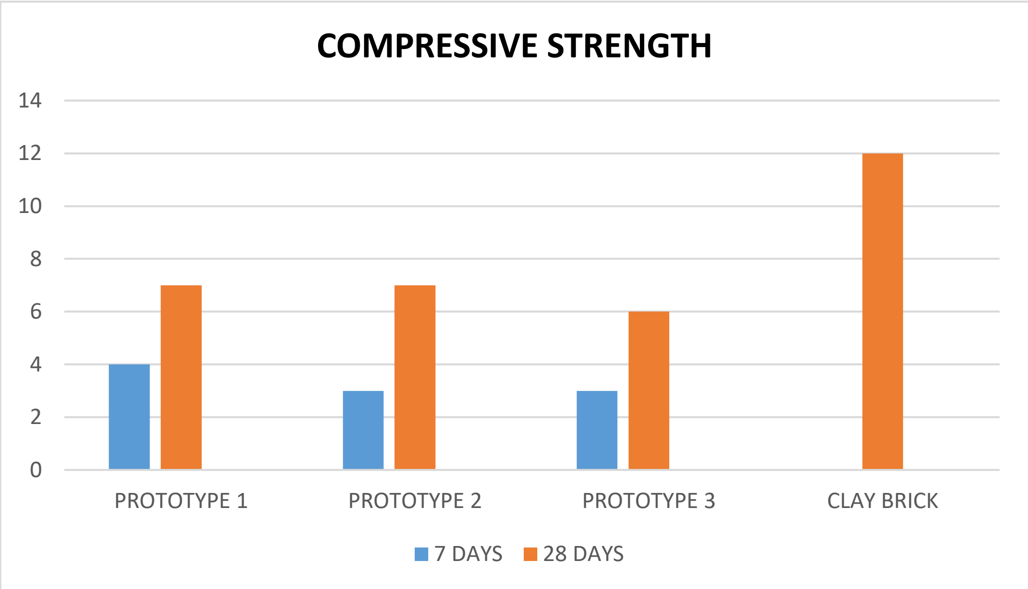
Compressive Strength

The compressive strength development of all specimens is summarized in Table 3. All prototypes showed significant strength gain from 7 to 28 days, demonstrating continued cementitious hydration despite partial replacement with waste materials.

Table 3: Compressive strength test results

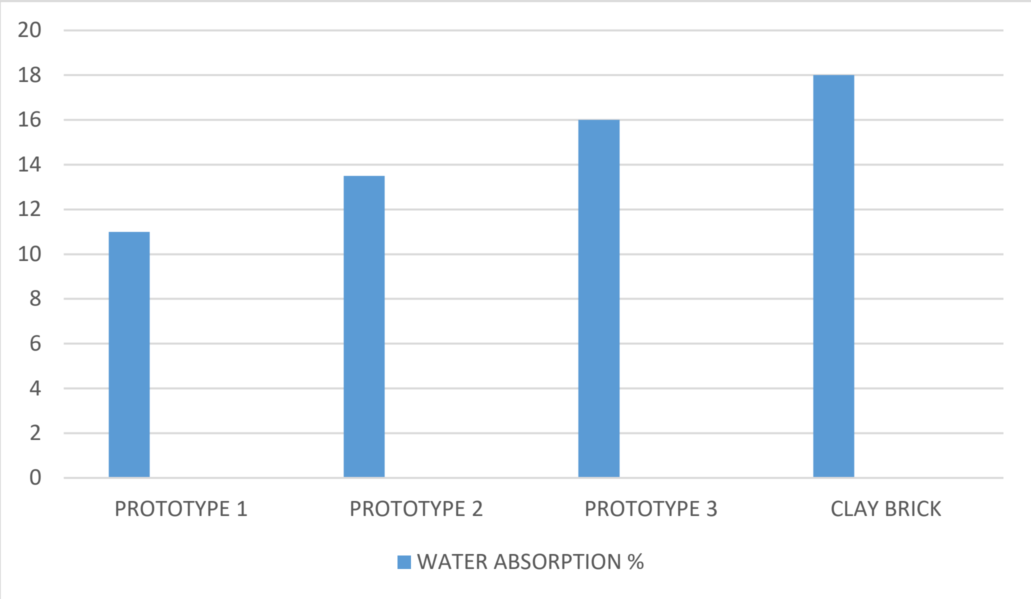
Mix ID	Replacement Level	7-Day (MPa)	28-Day (MPa)
Prototype 1	10% Biochar, 5% LDPE	4.0	7.0
Prototype 2	20% Biochar, 10% LDPE	3.0	7.0
Prototype 3	30% Biochar, 15% LDPE	3.0	6.0
Clay Brick	(Reference)	--	12.0

At 7 days, Prototype 1 showed the highest early strength (4.0 MPa), while Prototypes 2 and 3 registered lower values (3.0 MPa), indicating initial strength depression due to cement dilution by biochar and poor LDPE-matrix bonding. By 28 days, Prototypes 1 and 2 both reached 7.0 MPa, suggesting that the slower pozzolanic or filler effect of biochar compensated for early weakness in Prototype 2. Prototype 3 achieved a lower final strength of 6.0 MPa, indicating a threshold beyond which increased waste content adversely affects performance. Although lower than conventional clay brick (12.0 MPa), the 28-day strength of Prototypes 1 and 2 (7.0 MPa) meets standard requirements for non-load-bearing applications (typically 3.5-7.0 MPa).



Water Absorption

Water absorption is a key indicator of durability and resistance to frost action. The results, illustrated in Figure 2, show a clear trend of increasing absorption with higher waste content, from 11% for Prototype 1 to 16% for Prototype 3. This can be primarily explained by the nature of the additives: LDPE is hydrophobic and can create micro-voids at the aggregate-cement interface, while biochar is inherently porous. Interestingly, all prototypes exhibited lower absorption than the traditional clay brick (18%), which is a positive indicator of their potential durability against water-borne degradation. The 11% absorption of Prototype 1 is well within acceptable limits for building bricks.



Efflorescence and Hardness

Efflorescence was negligible to slight in Prototype 1 but became more pronounced in mixes with higher biochar content. This is likely because the biochar, derived from organic waste, can contain soluble salts that migrate to the surface with water evaporation. The surface hardness of the bricks showed a decreasing trend with increased LDPE content. Prototype 1 retained a 'Hard' rating, comparable to conventional bricks, as the low plastic content did not significantly compromise the matrix. However, the softer LDPE particles in Prototypes 2 and 3 made the surface more susceptible to scratching and abrasion ("Medium Hard" and "Soft-Medium", respectively).

Flammability

A significant finding of this study is the introduction of flammability due to the LDPE content. While the cementitious matrix is inert, the embedded plastic melts and burns when exposed to a direct flame. Prototype 1 (5% LDPE) showed low flammability, with only minor surface melting and no sustained burning. Prototypes 2 and 3 (10% and 15% LDPE) exhibited moderate to high effects, including charring, significant smoke emission, and sustained flaming after the heat source was removed. This necessitates a critical safety consideration, restricting the use of bricks with higher plastic content to non-fire-critical applications unless fire-retardant coatings or additives are incorporated in future work.

CONCLUSION

This study successfully demonstrates the technical feasibility of manufacturing cement bricks by incorporating waste LDPE plastic and biochar. The key findings are:

1. A replacement level of 10% cement with biochar and 5% sand with LDPE (Prototype 1) yields the most balanced set of properties, achieving a compressive strength of 7 MPa with low water absorption (11%) and minimal efflorescence, making it a viable alternative to first-class clay bricks for non-load-bearing applications.
2. Higher replacement levels, while reducing strength and increasing flammability, still produce bricks suitable for non-structural applications like garden walls, pavers, and partition walls, providing a valuable outlet for larger quantities of waste.
3. The process effectively valorizes two problematic waste streams, reducing the environmental footprint of brick production by conserving natural resources (sand and cement) and sequestering carbon within the building material itself.

This research promotes the principles of a circular economy in the construction sector. Future work should focus on long-term durability studies (e.g., freeze-thaw, acid attack), improving fire resistance through additives or coatings, and conducting a detailed life cycle assessment (LCA) to quantitatively validate the environmental benefits of this innovative approach

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