Sustainable Production of Stabilized Bricks from Black Cotton Soil using Pozzolanic Binders Derived from Industrial Waste

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ABSTRACT

The rapid growth of the construction sector has led to excessive consumption of topsoil, high fuel usage, and increased CO_2 emissions in traditional fired clay brick production. At the same time, expansive soils like Black Cotton Soil (BCS) pose significant challenges for construction due to their high swelling and shrinkage behaviour, while large quantities of industrial waste materials such as Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), and Bottom Ash continue to accumulate, causing environmental hazards. To address these issues, this project aims to develop sustainable stabilized bricks by utilizing BCS in combination with pozzolanic industrial waste, eliminating the need for energy-intensive kiln firing.

The methodology involved collecting raw materials locally, conducting geotechnical and chemical characterization tests, and preparing multiple mix proportions with varying percentages of stabilizers. The bricks were moulded using a standard size mould, air-dried initially, and then subjected to water curing for 7–28 days. The performance of the developed bricks was evaluated through compressive strength testing, water absorption, efflorescence, dimensional accuracy, and field inspection tests as per IS standards.

The experimental results demonstrated exceptionally low water absorption values ranging from 0.68% to 1.31%, indicating excellent durability and moisture resistance. However, the compressive strength values achieved (0.56–2.53 MPa) were lower than those of conventional fired bricks, making them suitable primarily for non-load-bearing applications. Among all prepared mixes, the optimized proportion containing higher stabilizer content showed the best strength and durability balance. The study concludes that stabilized BCS bricks offer a sustainable, cost-effective alternative for lightweight construction and contribute to environmental protection by reducing waste disposal and energy consumption. Further improvements in mix design, compaction techniques, and curing cycles are recommended to achieve structural-grade strength and wider practical applicability.

KEYWORDS

GGBS, Bottom ash, Cement, Water, Black cotton Soil, Basic Tests (Specific gravity , Liquid limit, Plastic limit, Standard proctor test, fineness)

INTRODUCTION

The construction industry is one of the fastest-growing sectors worldwide, supporting infrastructure development, economic growth, and urban expansion. However, this rapid development places heavy pressure on natural resources and the environment. Among the most commonly used construction materials, the traditional clay brick occupies a significant share due to its affordability, durability, and structural performance. Yet, the manufacturing of fired clay bricks relies largely on the extraction of fertile soil and the consumption of high energy during kiln firing. This process leads to severe environmental impacts such as land degradation, depletion of topsoil, deforestation for fuel, and high carbon emissions released into the atmosphere.

With increasing concerns about climate change and sustainable development, the construction industry is now experiencing a major shift toward eco-friendly and resource-efficient building materials. At the same time, the demand for bricks continues to rise, especially in developing countries like India where urbanization and population growth are rapidly expanding. Therefore, there is an urgent need to find alternative building materials that can replace or reduce the use of traditional fired bricks while maintaining the required engineering performance.

Black Cotton Soil (BCS), a widely available expansive soil in many regions of India, is generally unsuitable for construction due to its swelling and shrinkage characteristics. However, when stabilized with suitable additives, its engineering properties can be significantly improved. In parallel, large quantities of industrial waste materials containing pozzolanic properties—such as fly ash, rice husk ash, and GGBS—are being generated each year. Improper disposal of these wastes leads to land pollution and environmental hazards.

Utilizing Black Cotton Soil along with pozzolanic industrial by-products creates a sustainable opportunity to convert problematic soil and waste materials into valuable building products. Through proper stabilization, these ingredients can be transformed into durable and eco-friendly bricks without the need for high-temperature firing. This approach not only minimizes greenhouse gas emissions but also supports waste management and conserves natural clay resources.

Hence, the development of stabilized BCS bricks with pozzolanic binders aligns with global sustainability goals, circular economy principles, and green construction practices. This project focuses on exploring the production feasibility, mechanical strength, durability, and environmental benefits of such alternative bricks as a potential replacement for conventional fired clay bricks in the future.

substantial pathways for microplastics to enter soil ecosystems **[2]**. Once deposited, these particles persist for decades due to their non-biodegradable polymer composition, undergoing gradual fragmentation under UV radiation, mechanical stress, and biological activity.

The impacts of microplastic contamination on soil quality are multidimensional. Physically, microplastics alter soil porosity, bulk density, and water retention capacity. Chemically, they act as carriers of heavy metals, pesticides, and plastic additives such as phthalates and BPA, disrupting nutrient cycling **[4]**. Biologically, they reduce microbial diversity, enzyme activity, and earthworm populations, thereby threatening long-term agricultural productivity.

India's agricultural regions, particularly those practicing intensive plasticulture, are vulnerable to microplastic accumulation. However, systematic monitoring of microplastic contamination in Indian agricultural soils remains limited. This study addresses this gap by employing FTIR spectroscopy to identify and characterize microplastic residues in agricultural red soils from Ballari, Karnataka, with the aim of providing a scientific baseline for environmental monitoring and sustainable land management.

LITERATURE SURVEY

Pravin Patel Et Al (2014) : This paper presents a comprehensive experimental investigation into the stabilization of expansive black cotton soil using Rice Husk Ash (RHA), Fly Ash, and Lime. The study evaluates key geotechnical properties such as compaction behaviour, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and permeability. It was observed that individual additives reduced the liquid and plastic limits, while shrinkage limit improvements were minimal. RHA and Fly Ash reduced maximum dry density and increased optimum moisture content. The CBR value showed a significant increase when all three materials were combined, reaching 12.74%. UCS and cohesion values also improved with increasing stabilizer content. The study concluded that the optimal mix was 8% RHA, 20% Fly Ash, and 20% Lime. Overall, the treatment reduced pavement layer thickness and cost, making the stabilized soil suitable for road construction. The findings support the potential of using industrial and agro-waste as effective soil stabilizers.

Shannen Lyka S. Cruze Et Al.(2023): This study looks at how banana peel powder (BPP) and orange peel powder (OPP) can replace part of cement and affect its properties. The fruit peels are dried and powdered following specific standards. BPP has strong binding qualities and makes the cement stronger when used at 4%, 6%, and 8% replacement levels. On the other hand, adding OPP makes the cement weaker and does not meet the required standards. These results show that BPP can be used to make better cement, while OPP may not be suitable as a substitute right now. Using banana peels in cement can improve its strength and is a cheap, eco-friendly option for construction.

Alaa A. Shakir, Sivakumar Naganathan , Kamal Nasharuddin Mustapha(2013): This paper reports the findings of an investigation done on bricks made using fly ash (FA), quarry dust (QD), and billet scale (BS) by non conventional method. The procedure for producing the bricks includes mixing the constituents along with cement and water, and then forming the bricks within moulds without applying pressure over them. Unlike the traditional method of brick manufacturing, the new approach neither uses clay or shale nor requires high pressure on mould or high temperature kiln firing having remarkable environmental and ecological gain. Results for mechanical properties and durability were rewarding and promising. The optimum ratio of billet scale and fly ash is found to be 1:1, billet scale and quarry dust is 1:1. It is indicated that the bricks developed in this study can be used as an alternative to conventional bricks.

Wafaa Soliman1, Yasser M. Z.Ahmed 2, AhmedGhitas3, Abdel-Hamid El-Shater1 & M. Abdelhamid Shahat3 (2025): High energy consumption in buildings, particularly from air conditioning, is largely due to poor thermal insulation. This study explores the use of eggshell waste (as $CaCO_3$ filler) in clay bricks to enhance thermal resistance while addressing the dual challenge of waste disposal and sustainable construction. Bricks doped with varying eggshell content were evaluated for physicochemical and thermal properties. Notably, a 7 wt% eggshell addition resulted in improved porosity (52.7%), average pore size (78.8% increase), and reduced shrinkage (38.7%), enhancing both insulation and stability. A 10% eggshell content fired at 1100 °C showed the best thermal performance, with up to 50% reduction in thermal conductivity and significant drops in diffusivity and effusivity. XRD and EDX analyses confirmed beneficial structural changes due to siliceous melt formation and calcium incorporation. These findings suggest that incorporating eggshell waste into bricks improves energy efficiency and offers a sustainable solution to construction and waste management challenges.

METHODOLOGY

The methodology for producing stabilized bricks from black cotton soil starts with collecting essential materials such as black cotton soil, pozzolanic binder (like GGBS), cement, and water. The soil is then tested in the laboratory to determine its engineering properties, which helps in deciding whether it is suitable for brick making and how it should be treated. Based on the test results, the materials are proportioned carefully using a mix design so that the final bricks achieve adequate strength and durability. The mixing process is carried out in two stages—first dry mixing to ensure uniform distribution of binders, and then wet mixing by adding water to obtain a workable consistency. This mixture is then compressed into brick moulds using a manual press, which improves density and strength.

After moulding, the bricks are kept in shade for 1–2 days for initial setting, which helps them gain enough stiffness without cracking due to rapid drying. They are then cured for 14–21 days by regularly sprinkling water, allowing proper hydration of cement and binder, which significantly increases strength. After curing, the bricks are dried for a few days to remove excess moisture. Finally, the bricks undergo quality checks such as visual inspection, soundness, compressive strength, water absorption, and efflorescence tests to ensure they meet required standards. Once approved, the bricks are stacked properly for storage or construction use, ensuring durability and performance in practical applications.

EXPERIMENTAL RESULTS

The experimental bricks show significantly lower compressive strength than the reference red brick but far superior water absorption characteristics, indicating dense and durable units suitable mainly for non–load-bearing applications. While the red brick reaches 3.78 MPa, the experimental mixes range from 0.56 to 2.53 MPa, so they do not yet match the strength of conventional burnt clay bricks commonly used for structural masonry.

In terms of individual mixes, the 5th and 3rd designs are the best performers in compressive strength, achieving 2.53 MPa and 2.47 MPa respectively, followed by the 1st and 2nd mixes with 1.91 MPa and 1.52 MPa. The 4th mix records only 0.56 MPa, indicating inadequate bonding or compaction and making it unsuitable for practical brickwork without modification. This spread of values demonstrates that mix proportioning has a strong influence on strength and that further optimization can substantially improve performance.

Water absorption results present an opposite and very favourable trend for the experimental bricks. All five mixes show extremely low absorption between 0.68% and 1.31%, whereas the red brick absorbs about 25.69% water, reflecting much higher porosity. These values are far below typical limits for conventional bricks, indicating that the developed units are highly impermeable and likely to offer excellent resistance against moisture ingress, efflorescence, and related durability problems.

When strength and water absorption are evaluated together, the 5th mix emerges as the most balanced and promising composition, combining the highest compressive strength with the lowest water absorption. The 3rd mix ranks a close second, also offering high strength and very low absorption, and could be adopted where material availability or workability is more favourable for that proportion. The 1st and 2nd mixes may still be used for light, non–load-bearing masonry, while the 4th mix should be redesigned or discarded.

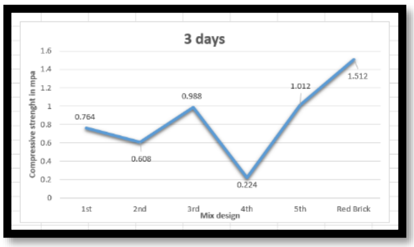
Overall, the study indicates that the alternative bricks are not yet suitable replacements for high-strength structural clay bricks but can be recommended for sustainable, non–load-bearing applications where moisture resistance and long-term durability are more critical than high compressive strength. With targeted improvements in stabilizer content, compaction, and curing, future iterations of the best-performing mixes (especially the 5th and 3rd) have clear potential to reach the minimum strength levels specified for standard burnt clay bricks while preserving their excellent low water absorption behaviour.

Table I: Mix Design

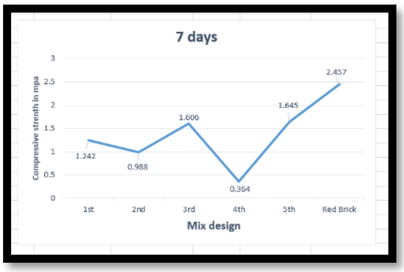
Materials	Mix Design				
	1st	2nd	3rd	4th	5th
BCS	40	50	60	60	60
BA(NTPC)	30	25	20	0	35
GGBS	25	20	15	35	0
Cement	5	5	5	5	5

Table 2: Compressive strength Results

3 Days		
SL.NO	Materials	Compressive strength in Mpa
1	BCS (40%),BA(30%),GGBS(25%),CEMENT(5%)	0.764
2	BCS (50%),BA(25%),GGBS(20%),CEMENT(5%)	0.608
3	BCS (60%),BA(20%),GGBS(15%),CEMENT(5%)	0.988
4	BCS (60%),BA(00%),GGBS(35%),CEMENT(5%)	0.224
5	BCS (60%),BA(35%),GGBS(00%),CEMENT(5%)	1.012

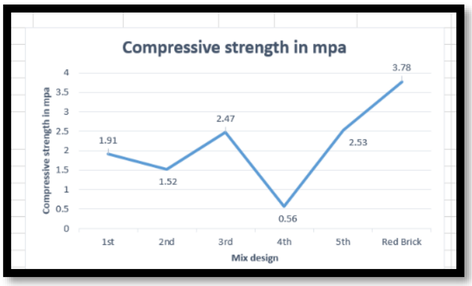


7 Days		
SL.NO	Materials	Compressive strength in Mpa
1	BCS (40%),BA(30%),GGBS(25%),CEMENT(5%)	1.242
2	BCS (50%),BA(25%),GGBS(20%),CEMENT(5%)	0.988
3	BCS (60%),BA(20%),GGBS(15%),CEMENT(5%)	1.606
4	BCS (60%),BA(00%),GGBS(35%),CEMENT(5%)	0.364
5	BCS (60%),BA(35%),GGBS(00%),CEMENT(5%)	1.645



14 Days		
SL.NO	Materials	Compressive strength in Mpa
1	BCS (40%),BA(30%),GGBS(25%),CEMENT(5%)	1.719
2	BCS (50%),BA(25%),GGBS(20%),CEMENT(5%)	1.368
3	BCS (60%),BA(20%),GGBS(15%),CEMENT(5%)	2.223
4	BCS (60%),BA(00%),GGBS(35%),CEMENT(5%)	0.504
5	BCS (60%),BA(35%),GGBS(00%),CEMENT(5%)	2.277

28 Days		
SL.NO	Materials	Compressive strength in Mpa
1	BCS (40%),BA(30%),GGBS(25%),CEMENT(5%)	1.91
2	BCS (50%),BA(25%),GGBS(20%),CEMENT(5%)	1.52
3	BCS (60%),BA(20%),GGBS(15%),CEMENT(5%)	2.47
4	BCS (60%),BA(00%),GGBS(35%),CEMENT(5%)	0.56
5	BCS (60%),BA(35%),GGBS(00%),CEMENT(5%)	2.53



CONCLUSION

The first major finding is that the experimental bricks show extremely low water absorption, ranging from 0.68% to 1.31%, which is far below both the reference red brick value of 25.69% and the typical limits specified in standards for conventional burnt clay bricks. This indicates a very dense and nearly impermeable microstructure that can offer excellent resistance to moisture ingress, dampness, and efflorescence, making the developed units highly durable in wet or aggressive environments.

The second major finding is that, despite their excellent durability characteristics, the experimental bricks attain relatively low compressive strength, with maximum values around 2.53 MPa that fall short of the minimum strength class for standard structural burnt clay bricks (about 3.5 MPa and above). Within the trial mixes, the 5th and 3rd designs stand out as the best performers, demonstrating the importance of mix proportioning and showing clear potential for further optimization to improve strength while retaining the advantageous low water absorption.

The practical significance of this study is that the developed bricks offer excellent resistance to moisture-related problems in masonry due to their extremely low water absorption, which can reduce issues like dampness, efflorescence, and deterioration in humid or rain-exposed environments. These characteristics make them particularly suitable for non–load-bearing and lightly loaded elements such as partition walls, façade panels, and cladding in basements or wet areas, where durability against water ingress is more critical than high compressive strength.

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