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*Review paper*

# CIGARETTE-BUTT-DERIVED FIRED CLAY BRICKS: PERFORMANCE, ENVIRONMENTAL SAFETY AND ARCHITECTURAL APPLICATIONS

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**Abstract**

*Cigarette butts (CBs), composed mainly of slowly degradable cellulose acetate, are a persistent and contaminated urban waste stream. Their incorporation into fired clay bricks offers a route for waste valorization and controlled pore formation. This review examines manufacturing, microstructure, engineering performance, environmental safety and architectural applicability of CB-derived fired clay bricks. Evidence from laboratory studies shows that low CB additions, commonly around 0.5-2.0 wt.%, reduce density and thermal conductivity, but increasing porosity also lowers compressive strength and raises water absorption. High-temperature firing destroys most organic constituents, while reported leachate concentrations from properly fired specimens remain below the regulatory thresholds used in the cited studies. The material is therefore most promising where mixture composition and firing conditions are optimized for the required masonry performance. Industrial-scale validation, long-term field monitoring and comparative life-cycle assessment remain necessary before broad specification in buildings.*

**Key words:** *cigarette butts; fired clay bricks; cellulose acetate; circular economy; thermal insulation*

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## 1. INTRODUCTION

The construction sector is facing increasing pressure to reduce its environmental impact through the adoption of sustainable materials and circular economy principles. Simultaneously, the generation of persistent solid waste continues to grow, creating significant challenges for waste management systems worldwide. Among the most widespread forms of urban litter are discarded cigarette butts, which represent the most frequently collected anthropogenic waste item in streets, parks, beaches and public spaces. It is estimated that approximately 5.7 trillion cigarettes are consumed annually, with the majority of filters being improperly discarded into the environment rather than collected through organized waste management systems [1,2].

Conventional cigarette filters are manufactured predominantly from cellulose acetate, a thermoplastic polymer characterized by high chemical stability and extremely slow biodegradation. Depending on environmental conditions, complete degradation may require several years or even decades. During this period, cigarette butts gradually release numerous hazardous substances, including nicotine, heavy metals, polycyclic aromatic hydrocarbons and other toxic organic compounds accumulated during tobacco combustion. Consequently, discarded cigarette filters represent not only an aesthetic problem but also a potential source of soil and water contamination, negatively affecting terrestrial and aquatic ecosystems [2-4].

The incorporation of cigarette butts into fired clay bricks offers several technological advantages. During firing, cellulose acetate undergoes thermal decomposition, producing uniformly distributed pores throughout the ceramic body. This controlled increase in porosity decreases bulk density and significantly improves thermal insulation, thereby enhancing the energy efficiency of masonry walls. At carefully optimized replacement levels, the reduction in compressive strength remains within the ranges reported as potentially suitable for selected load-bearing or non-load-bearing masonry applications [1,5,6].

The objective of this review is to provide a comprehensive evaluation of cigarette-butt-derived fired clay bricks by critically examining manufacturing technologies, microstructural evolution, engineering performance, environmental safety and potential architectural applications. Particular emphasis is placed on understanding the relationships between processing parameters, pore development and final material properties, thereby providing an integrated assessment of the feasibility of this innovative ceramic material for sustainable building construction.

## 2. CIGARETTE BUTTS AS A SUSTAINABLE ADDITIVE IN FIRED CLAY BRICKS

### 2.1. Chemical Composition and Physicochemical Characteristics of Cigarette Filters

Cigarette filters are primarily manufactured from cellulose acetate, a thermoplastic derivative of cellulose obtained through the acetylation of natural cellulose fibers. Cellulose acetate typically accounts for more than 95 wt.% of the filter composition,

while the remaining fraction consists of plasticizers, predominantly triacetin, paper wrapping materials and trace additives introduced during industrial production. The fibrous structure of cellulose acetate provides the filtration efficiency required during cigarette consumption but also contributes to its remarkable persistence in the environment after disposal [2,4].

Experimental studies consistently report that only relatively small quantities of cigarette butts are necessary to modify brick properties. Replacement levels between 0.5 and 2.0 wt.% have generally produced the most favorable balance between reduced density, improved thermal insulation and acceptable mechanical performance. At higher concentrations, excessive pore formation may significantly reduce compressive strength and increase water absorption, thereby limiting practical applications for structural masonry units [1,5,6].

## 2.2. Behaviour of Cigarette Butts during Brick Manufacturing

The incorporation of cigarette butts into clay bricks modifies the manufacturing process primarily through the thermal decomposition of cellulose acetate during firing. Unlike conventional mineral additives, cigarette filters do not participate directly in ceramic sintering but function as sacrificial pore-forming agents. As the firing temperature increases, the organic component decomposes and volatilizes, generating a controlled porous network that significantly influences the physical and thermal characteristics of the final ceramic product [1,3].

During firing, several temperature-dependent transformations occur simultaneously. Initially, physically bound water evaporates, followed by the dehydroxylation of clay minerals. At temperatures above approximately 250-300 °C, cellulose acetate begins to thermally degrade, releasing volatile gaseous products that gradually escape through the ceramic body. As firing progresses toward temperatures between 900 and 1050 °C, ceramic sintering densifies the mineral matrix while preserving the pores created by polymer decomposition. The resulting microstructure consists of a dense ceramic skeleton containing numerous fine, uniformly distributed pores that contribute to lower density and reduced thermal conductivity [1,5].

## 2.3. Manufacturing Technology of Cigarette-Butt-Derived Fired Clay Bricks

The manufacturing process consists of five principal stages: raw material preparation, mixing, shaping, drying and firing. Natural clay is first processed to obtain a homogeneous particle-size distribution suitable for extrusion or molding. In parallel, collected cigarette butts undergo pretreatment involving separation of residual tobacco, washing, drying and mechanical shredding. The treated fibers are then incorporated into the clay mixture at predetermined replacement levels, typically ranging between 0.5 and 2.0 wt.%, depending on the targeted engineering performance of the final product [3,5].

The firing stage governs the final microstructure and performance of cigarette-butt-derived bricks. Depending on the clay composition, maximum firing temperatures typically range between 900 and 1050 °C. During heating, the organic components of

cigarette filters decompose completely, generating gases that escape from the ceramic matrix and leave behind a finely distributed pore network. Simultaneously, clay minerals undergo sintering and partial vitrification, producing a dense ceramic framework that surrounds the newly formed pores. The balance between pore generation and ceramic densification ultimately determines density, compressive strength, thermal conductivity and water absorption of the finished bricks [1,5,7].

Careful optimization of processing parameters is essential for achieving satisfactory engineering performance. Experimental studies demonstrate that firing temperature, heating rate, soaking time and cigarette-butt content collectively control pore morphology and ceramic densification. Higher firing temperatures generally improve sintering and mechanical strength but may also reduce total porosity through enhanced vitrification. Conversely, excessive waste incorporation increases pore connectivity, leading to higher water absorption and lower compressive strength. Therefore, manufacturing parameters should be optimized simultaneously rather than independently to obtain the most favorable balance between structural integrity and thermal insulation [1,3,6].

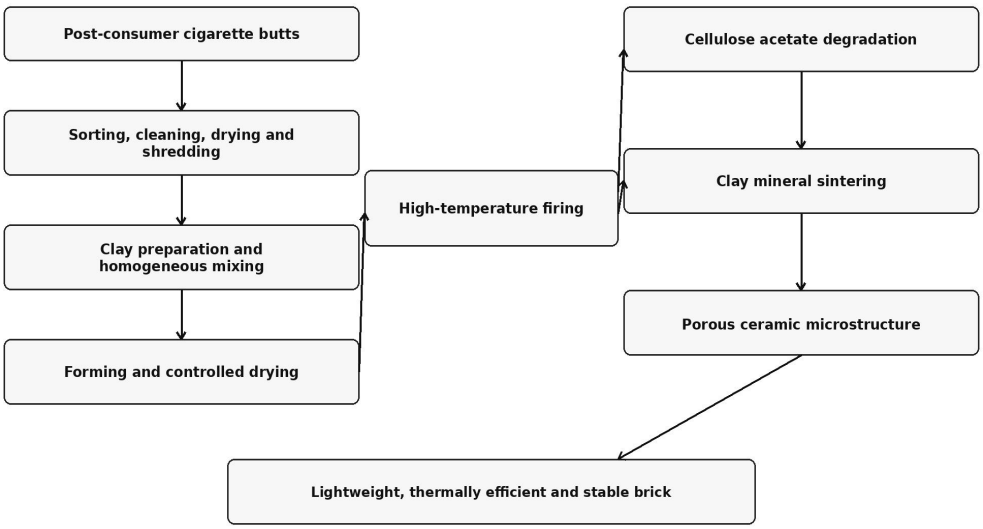



*Figure 1. Technological and physicochemical pathway for manufacturing cigarette-butt-derived fired clay bricks (authors' illustration).*

*Table 1. Comparison of conventional and cigarette-butt-derived fired clay bricks.*

| Aspect | Conventional fired clay brick | CB-derived fired clay brick |
|---|---|---|
| Raw materials | Natural clay and standard additives | Natural clay with 0.5-2.0 wt.% pre-treated CB waste |
| Firing mechanism | Clay sintering and vitrification | Sintering plus cellulose-acetate decomposition and pore formation |
| Bulk density | Reference density | Generally reduced because of additional pores |
| Thermal conductivity | Higher for denser ceramic body | Lower when fine air-filled pores are uniformly distributed |
| Main limitation | Energy-intensive firing | Strength and water absorption must be controlled by dosage and firing |

## 3. STRUCTURE-PROPERTY RELATIONSHIPS IN CIGARETTE-BUTT-DERIVED FIRED CLAY BRICKS

### 3.1. Microstructural Evolution

The engineering performance of fired clay bricks containing cigarette butts is governed primarily by the evolution of their microstructure during thermal processing. Unlike conventional dense ceramic materials, the incorporation of cellulose acetate fibers intentionally modifies the internal pore system, producing lightweight ceramic products with improved thermal insulation characteristics. The final microstructure results from the combined effects of clay mineral transformations, sintering mechanisms and the thermal degradation of cigarette filters during firing [1,3].

Scanning electron microscopy reported in numerous experimental investigations demonstrates that low cigarette-butt contents produce a relatively uniform distribution of fine, isolated pores surrounded by a dense ceramic matrix. These closed pores reduce thermal conductivity by limiting heat transfer through the material while only slightly affecting its mechanical resistance. As the waste content increases, both pore diameter and pore connectivity become progressively larger, producing a more heterogeneous internal structure characterized by interconnected voids and thinner ceramic walls [5,6].

Microstructural observations further indicate that the pores generated by cellulose acetate decomposition are generally rounded and uniformly distributed when the waste content remains within the recommended range. Rounded pores are less detrimental to compressive strength than elongated or irregular voids because they produce lower stress concentrations under mechanical loading. Consequently, optimizing both pore size distribution and pore geometry is essential for achieving an appropriate balance between thermal insulation and structural performance [3,6].

### 3.2. Bulk Density

During firing, cellulose acetate fibers are almost completely decomposed, leaving numerous microscopic voids distributed throughout the ceramic matrix. These pores reduce the volume fraction occupied by solid material, thereby decreasing the overall density of the fired brick. Experimental investigations consistently demonstrate that density reduction is approximately proportional to the amount of incorporated cigarette-butt waste, although the exact relationship depends on clay composition, firing temperature and the degree of ceramic vitrification achieved during sintering [1,5].

However, density should not be minimized without considering its influence on other engineering properties. Very low densities generally indicate excessive pore connectivity and reduced ceramic skeleton continuity, which may adversely affect compressive strength, durability and water resistance. Therefore, the optimum manufacturing strategy aims to achieve moderate density reduction while preserving sufficient structural integrity for long-term service under mechanical and environmental loading [3,7].

### 3.3. Compressive Strength

The reduction in compressive strength is primarily associated with the increase in total porosity generated during the thermal decomposition of cellulose acetate. As the organic fibers volatilize during firing, they leave behind pores that reduce the effective load-bearing cross-sectional area of the ceramic matrix. Under compressive loading, stresses become concentrated around these pores, facilitating crack initiation and propagation. Consequently, compressive strength generally decreases with increasing cigarette-butt content [1,5].

Despite this reduction, the relationship between porosity and strength is not purely linear. When cigarette-butt additions remain relatively low, typically between 0.5 and 2.0 wt.%, the pores are generally small, rounded and uniformly distributed throughout the ceramic body. This microstructure limits stress concentration and allows the surrounding vitrified ceramic matrix to maintain sufficient structural continuity. As a result, the decrease in compressive strength is moderate and remains within ranges reported as potentially suitable for selected masonry applications [5,6].

### 3.4. Water Absorption

The increase in water absorption is directly associated with the formation of additional pores following the thermal decomposition of cellulose acetate. As the organic fibers volatilize during firing, they generate a porous network capable of storing and transporting water. The extent of water uptake depends not only on total porosity but also on pore size distribution, pore connectivity and the degree of ceramic vitrification achieved during sintering [1,5].

Experimental studies consistently demonstrate that water absorption increases with increasing cigarette-butt content. Bricks containing low replacement levels, generally up to approximately 1 wt.%, exhibit only moderate increases in water absorption because the newly formed pores remain predominantly isolated or only weakly interconnected. Under these conditions, the ceramic matrix maintains sufficient continuity to limit capillary water transport while simultaneously providing improved thermal insulation through the presence of entrapped air [5,6].

### 3.5. Thermal Conductivity

The reduction in thermal conductivity results primarily from the low thermal conductivity of air contained within the pores generated during the thermal decomposition of cellulose acetate. Since air is a much poorer heat conductor than the ceramic matrix, increasing the volume of uniformly distributed closed pores effectively interrupts heat flow through the brick. This mechanism explains the consistent decrease in thermal conductivity reported by experimental investigations as cigarette-butt content increases [1,5].

Several studies have demonstrated that relatively small additions of cigarette butts produce measurable improvements in thermal insulation without causing unacceptable reductions in mechanical performance. Bricks containing approximately 1 wt.% cigarette butts typically exhibit a significant decrease in thermal conductivity while

maintaining compressive strength within the limits required for structural masonry applications. This balance between mechanical resistance and thermal efficiency represents one of the principal advantages of cigarette-butt-derived fired clay bricks over conventional dense ceramic products [5,6].

### 3.6. Durability

The long-term performance of fired clay bricks is strongly influenced by their pore system. Uniformly distributed, predominantly closed pores generated by the thermal decomposition of cellulose acetate reduce density and improve thermal insulation without significantly compromising structural stability. In contrast, excessive pore connectivity facilitates moisture penetration, increasing the susceptibility of the material to weathering processes such as freeze-thaw deterioration, salt crystallization and repeated wetting-drying cycles. Consequently, maintaining a controlled pore structure is essential for achieving satisfactory durability [1,5].

Freeze-thaw resistance is particularly important in temperate climates because water retained in connected pores can generate hydraulic pressure and initiate microcracking. The available evidence establishes the importance of controlling open porosity, but does not yet provide a sufficient basis for a general long-term freeze-thaw rating of CB-derived bricks. Durability should therefore be verified for the intended exposure class and manufacturing formulation [5,6].

## 4. ENVIRONMENTAL SAFETY OF CIGARETTE-BUTT-DERIVED FIRED CLAY BRICKS

### 4.1. Thermal Degradation and Immobilization of Contaminants

During the production of fired clay bricks, cigarette butts are exposed to temperatures typically ranging from 900 to 1050 °C. At these temperatures, cellulose acetate undergoes complete thermal decomposition, while the majority of organic pollutants are oxidized into gaseous products that are removed during firing. Thermogravimetric and chemical analyses reported in recent studies demonstrate that the organic fraction of cigarette filters is almost entirely destroyed before the completion of the firing cycle, preventing its persistence within the final ceramic product [1,5].

Simultaneously, mineral transformations occurring within the clay matrix promote the stabilization of inorganic contaminants. As sintering progresses, clay particles undergo partial vitrification, producing a dense ceramic framework capable of physically encapsulating trace metallic elements. Some contaminants also become chemically incorporated into newly formed crystalline or amorphous ceramic phases, further reducing their mobility. Consequently, the final fired brick functions as a stable ceramic matrix in which potentially hazardous inorganic constituents remain immobilized throughout the service life of the material [3,6].

### 4.2. Heavy Metal Leaching Behaviour

Experimental leaching studies consistently demonstrate that properly fired cigarette-butt-derived bricks release only negligible quantities of heavy metals when subjected to standardized leaching procedures. The extremely low concentrations measured in aqueous extracts indicate that the ceramic matrix effectively limits contaminant mobility through a combination of physical encapsulation and chemical immobilization. As a result, the concentrations of released metals generally remain well below internationally accepted regulatory limits for construction materials and inert waste products [3,6].

### 4.3. Life-Cycle Considerations and Sustainability Assessment

The replacement of a small fraction of natural clay with cigarette-butt waste also contributes to the conservation of non-renewable mineral resources. Although the replacement levels are relatively low, widespread industrial implementation could substantially decrease the cumulative demand for virgin clay extraction over time. Reduced extraction activities may lessen land degradation, habitat disturbance and the environmental impacts associated with quarrying operations, thereby improving the overall sustainability profile of ceramic manufacturing [5,6].

From the perspective of circular economy principles, cigarette-butt-derived fired clay bricks represent an example of industrial symbiosis in which problematic municipal waste is transformed into a durable construction product with long service life. Rather than following the traditional linear model of extraction, consumption and disposal, this approach promotes resource circulation by maintaining material value within the production cycle. Such strategies are increasingly encouraged by international sustainability policies seeking to reduce waste generation, improve resource efficiency and decrease greenhouse gas emissions throughout the construction industry [2,8].

## 5. ARCHITECTURAL APPLICATIONS OF CIGARETTE-BUTT-DERIVED FIRED CLAY BRICKS

One of the principal architectural advantages of cigarette-butt-derived bricks is their contribution to energy-efficient building envelopes. Because the incorporation of cigarette butts reduces thermal conductivity through controlled pore formation, masonry walls constructed with these bricks exhibit improved thermal resistance compared with conventional fired clay products. Improved insulation decreases heat transmission through external walls, thereby reducing heating demand during winter and cooling demand during summer. These characteristics contribute directly to lower operational energy consumption and reduced greenhouse gas emissions throughout the building life cycle [1,5].

The lower bulk density of cigarette-butt-derived bricks also offers important structural and architectural benefits. Lightweight masonry units reduce permanent loads acting on foundations and supporting structural systems, facilitating more efficient structural design while simplifying transportation and on-site construction.

Reduced material weight improves handling during installation and may contribute to shorter construction times, particularly in low-rise and medium-rise residential buildings where masonry remains one of the dominant wall construction systems [3,6].

From an architectural perspective, CB-derived units could be integrated into conventional masonry systems if their dimensions, strength class, moisture behaviour and compatibility with mortars are demonstrated under the applicable product and design standards. Their use should therefore be specified by performance class rather than assumed to be interchangeable with every conventional fired clay unit [5,7].

Despite these advantages, practical implementation should remain based on optimized manufacturing conditions that ensure consistent engineering performance. Appropriate control of cigarette-butt content, firing temperature and quality assurance procedures is essential to maintain the balance between structural capacity, durability and thermal efficiency required for long-term architectural applications. When these requirements are satisfied, cigarette-butt-derived fired clay bricks represent a technically feasible and environmentally responsible alternative to conventional ceramic masonry materials.

## 6. CONCLUSIONS

The thermal decomposition of cellulose acetate during firing produces a controlled porous microstructure that significantly influences the engineering performance of the final material. Properly optimized cigarette-butt contents, generally around 1 wt.%, reduce bulk density and thermal conductivity while maintaining compressive strength, water absorption and durability within the limits required for fired clay masonry applications. The resulting lightweight ceramic products offer improved thermal insulation, contributing to enhanced building energy efficiency and reduced operational energy consumption.

High-temperature ceramic processing also provides an effective mechanism for environmental protection. Organic contaminants present in cigarette filters are almost completely decomposed during firing, whereas residual inorganic constituents become immobilized within the vitrified ceramic matrix. Experimental investigations report low heavy metal leaching from properly manufactured bricks, supporting environmental acceptability under the leaching conditions evaluated in the cited studies.

Although the available scientific evidence confirms the technical feasibility of this recycling approach, successful industrial implementation requires careful optimization of manufacturing parameters, including waste content, pretreatment procedures and firing conditions. Future research should focus on large-scale industrial production, long-term field performance and comprehensive life-cycle assessment to facilitate broader commercial adoption.

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