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The Research Progress and Application Prospects of Bamboo Leaf Ash Concrete

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Abstract

This paper provides a comprehensive review of the research progress and application prospects of bamboo leaf ash (BLA) concrete. By analyzing the physicochemical properties of bamboo leaf ash and its mechanisms of action in concrete, the paper discusses the effects of bamboo leaf ash on the workability, mechanical properties, and durability of concrete. The research indicates that bamboo leaf ash, as a cement replacement material, offers significant environmental and economic benefits, with an optimal replacement rate ranging from 8% to 12%. Bamboo leaf ash concrete excels in enhancing compressive strength, improving durability, and reducing self-weight. However, further investigation is required to fully understand its long-term performance and microscopic mechanisms. This paper provides a theoretical foundation and practical guidance for the further research and application of bamboo leaf ash concrete.

Keywords

Bamboo leaf ash; concrete; cement alternative materials; mechanical properties; durability; environmental benefits.

1. Introduction

With the rapid development of the global construction industry, the use of concrete as a building material has continued to increase. Approximately 11.5 billion tons of concrete are produced annually worldwide, requiring 1.5 billion tons of cement, 1 billion tons of water, and 9 billion tons of aggregates [1]. However, cement production not only consumes vast amounts of energy but also releases large quantities of carbon dioxide, presenting a significant challenge in addressing global climate change. Therefore, reducing cement consumption and developing alternative materials have become important issues for both academia and industry.

The use of admixtures in concrete is a common method to reduce cement usage and improve concrete performance. This is primarily due to the reaction between silica (SiO_2) and calcium hydroxide ($Ca(OH)_2$) produced during the cement hydration process, forming calcium silicate hydrate (C-S-H). Additionally, the fine particles of pozzolans act as fillers, promoting a more uniform cement matrix and refining the concrete's pore structure [2]. In recent years, research on using biomass ash as a concrete admixture has increased, as biomass ash typically exhibits pozzolanic effects that meet specifications and makes full use of agricultural waste. Bamboo leaf ash, a biomass ash with pozzolanic activity, has gradually gained attention. The widespread distribution of bamboo globally and its high yield as agricultural waste make bamboo leaf ash a promising alternative cementitious material. Bamboo leaf ash not only reduces cement usage but also effectively enhances the mechanical properties and durability of concrete. Moreover, its use helps to reduce the accumulation of agricultural waste, decrease environmental pollution, and contribute to sustainable development.

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This paper aims to comprehensively summarize the research findings on bamboo leaf ash concrete, analyze the effects of bamboo leaf ash on concrete performance, and evaluate the potential of bamboo leaf ash as a cement replacement material.

2. Chemical Composition and Mechanism of Action of Bamboo Leaf Ash

2.1. Chemical Composition of Bamboo Leaf Ash

Bamboo leaf ash is obtained by burning bamboo leaves, and its main components include oxides such as silica (SiO_2), calcium oxide (CaO), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) [3], with silica content being particularly important. The silica content of bamboo leaf ash typically exceeds 70%, which gives it strong pozzolanic reactivity. This allows it to react with lime (CaO) in cement to form calcium silicate hydrate (C-S-H), thereby enhancing the strength of concrete. However, the chemical composition and pozzolanic activity of bamboo leaf ash are significantly influenced by factors such as the type of bamboo, its growing environment, and the calcination temperature. Dwivedi et al. [4] found that bamboo leaf ash, when calcined at 600°C for 2 hours, exhibited good pozzolanic activity. Odeyemi et al. [5] discovered that calcining bamboo leaf ash at 700°C resulted in a silica content greater than 72%, indicating that this calcination temperature was optimal. Umoh et al. [6] observed that bamboo leaf ash calcined at 500°C for 2 hours demonstrated strong pozzolanic activity.

Studies have shown that the pozzolanic activity of bamboo leaf ash is highest when the combustion temperature is between 500°C and 700°C, with a combustion time of 2 hours. Excessively high combustion temperatures may lead to the crystallization of silica in the bamboo leaf ash, reducing its reactivity. Therefore, controlling the combustion conditions is crucial for obtaining high-quality bamboo leaf ash.

Table 2.1. Chemical Composition of Bamboo Leaf Ash

BLA	SiO_2	CaO	Al_2O_3	Fe_2O_3	K_2O	MgO	LOI
[4]	75.90	7.47	4.13	1.22	5.62	1.85	-
[5]	72.81	2.50	3.49	2.00	2.09	0.17	5.71
[6]	72.25	4.23	4.08	1.97	3.15	1.01	2.93

2.2. The role mechanism of bamboo leaf ash in concrete

The mechanisms of bamboo leaf ash in concrete mainly include pozzolanic reaction and filling effect. The pozzolanic reaction refers to the process in which the active silica in bamboo leaf ash reacts with calcium hydroxide ($Ca(OH)_2$), a product of cement hydration, to form calcium silicate hydrate (C-S-H) gel. This reaction not only consumes the calcium hydroxide generated during cement hydration but also produces more C-S-H gel, thereby enhancing the strength and durability of the concrete.

The filling effect refers to the process in which the bamboo leaf ash particles fill the voids between the cement particles, improving the compactness and strength of the concrete. Bamboo leaf ash particles are typically smaller than cement particles and can better fill the voids in the cement paste, reducing the porosity and increasing the density of the concrete. Additionally, the filling effect of bamboo leaf ash particles can improve the workability of the concrete, reducing water bleeding and segregation.

The combined action of the pozzolanic reaction and filling effect of bamboo leaf ash significantly enhances the mechanical properties and durability of the concrete. Studies have shown that bamboo leaf ash concrete exhibits superior compressive strength, flexural strength, and impermeability compared to ordinary concrete. Furthermore, bamboo leaf ash can improve the

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concrete's resistance to sulfate attack and chloride ion permeability, thereby extending the service life of the concrete.

3. The Effect of Bamboo Leaf Ash on The Workability of Concrete

Bamboo leaf ash has a significant impact on the workability of concrete, particularly in terms of slump. Slump is an important indicator of the flowability and plasticity of concrete, which directly affects its workability during construction. Onikeku et al. [7] found through experiments that the incorporation of bamboo leaf ash affected the slump of concrete, showing a trend of slight initial increase followed by a decrease. Hnin Htet et al. [8] added bamboo leaf ash to concrete with different water-to-cement ratios and observed a continuous decrease in slump across all mixtures.

The research indicates that the addition of bamboo leaf ash typically reduces the slump of concrete, primarily due to the larger specific surface area of bamboo leaf ash particles, which adsorb more water, leading to a reduction in concrete flowability. However, an appropriate amount of bamboo leaf ash can improve the density of the concrete through the filling effect, reducing water bleeding and segregation, thereby enhancing the uniformity and stability of the concrete.

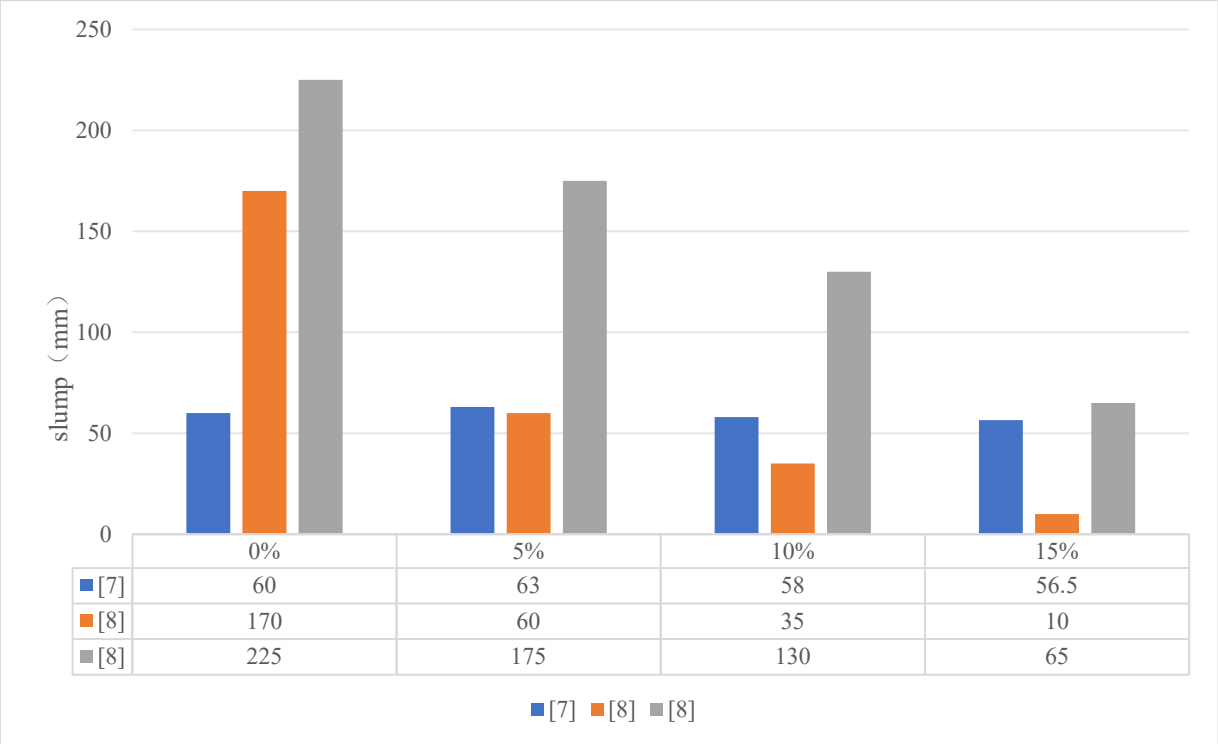

Figure 3. The slump of concrete

4. The Effect of Bamboo Leaf Ash on The Mechanical Properties of Concrete

Bamboo leaf ash has a significant impact on the mechanical properties of concrete, particularly in terms of compressive strength, flexural strength, and splitting tensile strength. Compressive strength is an important indicator of the ability of concrete to withstand pressure, directly affecting the structural safety of concrete. Flexural strength is a key measure of concrete's ability to resist bending stress, directly influencing its cracking resistance. Splitting tensile

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strength is an essential indicator of concrete's ability to resist tensile forces, which directly affects its cracking resistance and durability.

4.1. Compressive strength

Onikeku et al. [7] found that the compressive strength of concrete showed an initial increase followed by a decrease with the increase in bamboo leaf ash content at different curing ages (7, 28, 56, and 90 days). The compressive strength peaked at a bamboo leaf ash content of 10% at 28 days. Hnin Htet et al. [8] observed a similar trend, except that at 28 days, the maximum compressive strength was achieved with a bamboo leaf ash content of 5%. These studies suggest that bamboo leaf ash can effectively improve the mechanical properties of concrete within a certain replacement range, but excessive replacement may have a negative impact on the performance.

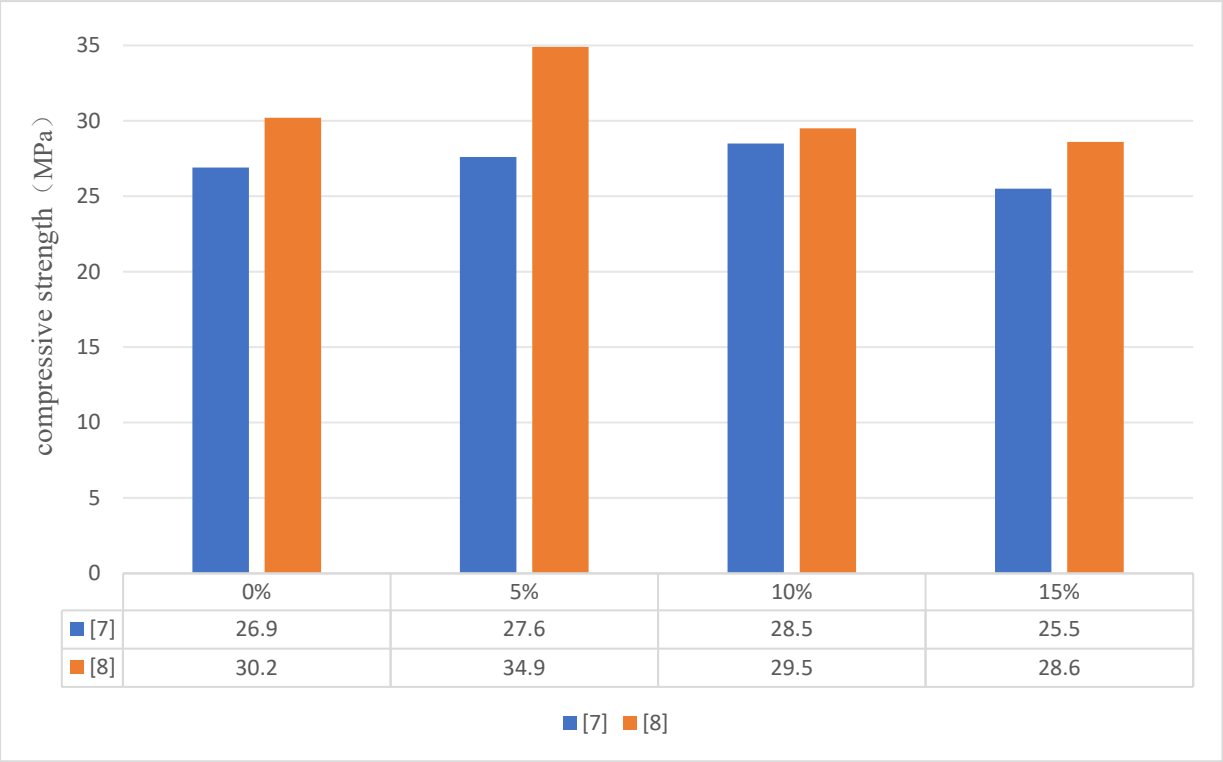

Figure 4.1. Concrete compressive strength

4.2. Splitting tensile strength and bending strength

Onikeku et al. [7] found that at 28 days, the splitting tensile strength of concrete initially increased and then decreased, with the maximum strength observed at a bamboo leaf ash content of 10%. Nduka et al. [9] reached a different conclusion, noting through experiments that the splitting tensile strength of concrete consistently decreased at 28 days, with the control group showing the highest tensile strength. Odeyemi et al. [5] found that at 28 days, the splitting tensile strength of concrete initially decreased, then increased, and finally decreased again, with the maximum strength observed at a bamboo leaf ash content of 10%. These studies indicate that the splitting tensile strength of bamboo leaf ash concrete generally decreases with increasing bamboo leaf ash content. When the bamboo leaf ash content exceeds 15%, the splitting tensile strength significantly weakens.

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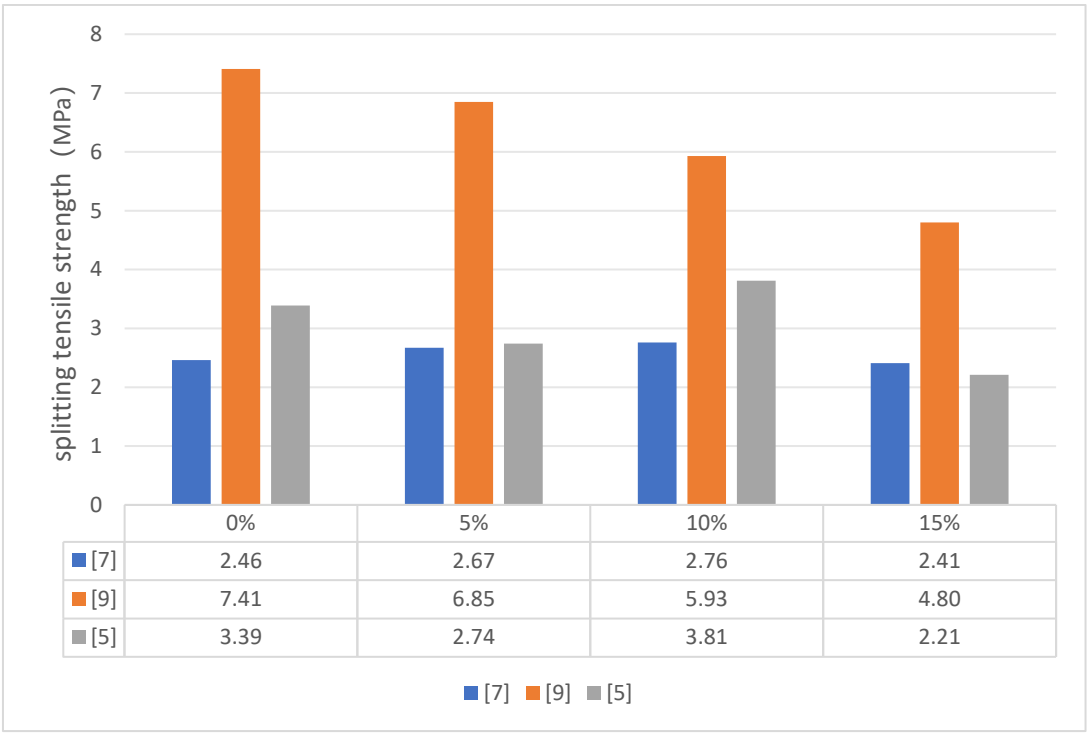

Figure 4.2. Concrete splitting tensile strength

Both Onikeku et al. [7] and Nduka et al. [9] found that at 28 days, the flexural strength of concrete exhibited an initial increase followed by a decrease, with the maximum strength observed at a bamboo leaf ash content of 10%. These studies suggest that the flexural strength of bamboo leaf ash concrete increases with the addition of bamboo leaf ash, but when the bamboo leaf ash content exceeds 10%, the improvement in flexural strength gradually diminishes.

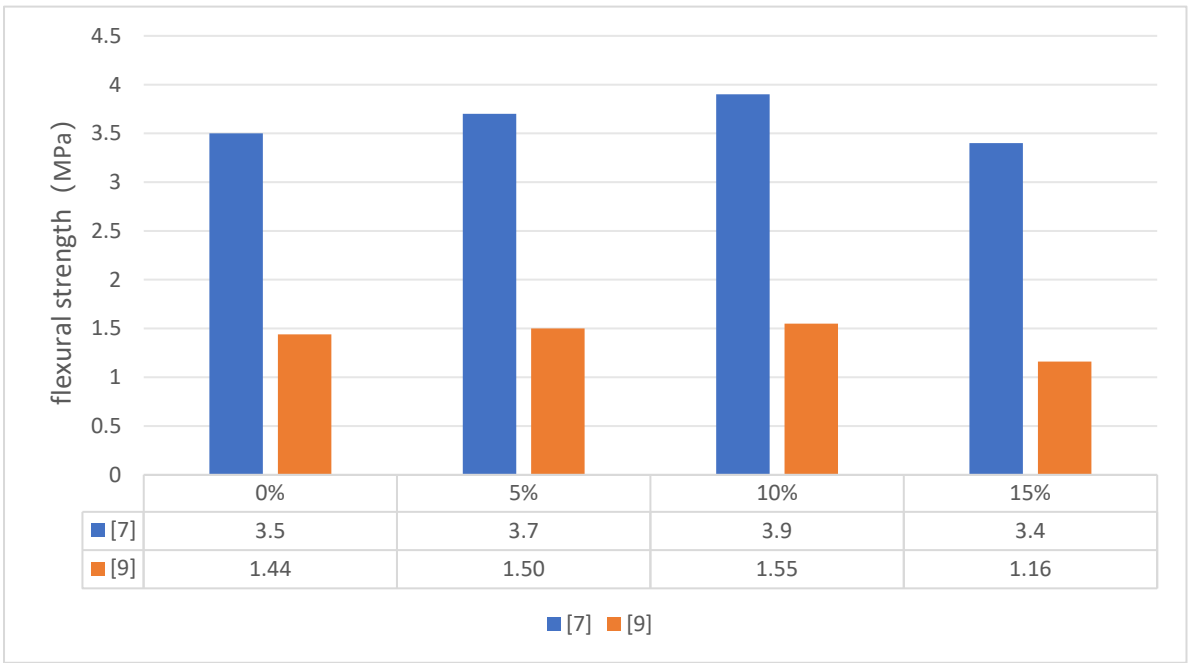

Figure 4.3. Concrete bending strength

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5. The Effect of Bamboo Leaf Ash on The Durability Performance of Concrete

Bamboo leaf ash, as a pozzolanic material, not only enhances the mechanical properties of concrete but also improves its durability. Studies have shown that bamboo leaf ash can significantly reduce the water absorption of concrete. This characteristic is particularly important for improving the concrete's resistance to corrosion and freeze-thaw damage.

5.1. Water absorption rate

The water absorption rate of concrete is an important performance indicator that affects its durability, frost resistance, and corrosion resistance. A high water absorption rate typically indicates a higher porosity within the concrete, which may make the concrete more susceptible to damage from water, chemicals, or freeze-thaw cycles, thus compromising its durability. Conversely, a low water absorption rate generally indicates denser concrete with greater durability.

Onikeku et al. [7] found that the water absorption rate of concrete initially decreased and then increased with increasing bamboo leaf ash content. When the bamboo leaf ash content exceeded 10%, the water absorption rate increased, which may be due to an excessive bamboo leaf ash content inhibiting the cement hydration process, thereby reducing the formation of calcium silicate hydrate (C-S-H) and affecting the concrete's density. Umoh et al. [6] observed a similar trend, with the water absorption rate initially decreasing and then increasing as the bamboo leaf ash content increased. The minimum water absorption rate occurred at a bamboo leaf ash content of 10%, which corresponded to the highest density of the concrete. These studies suggest that the water absorption rate of bamboo leaf ash concrete increases within a certain range as the bamboo leaf ash content increases. This is primarily due to the filling effect of bamboo leaf ash particles, which reduces the porosity of the concrete and improves its density.

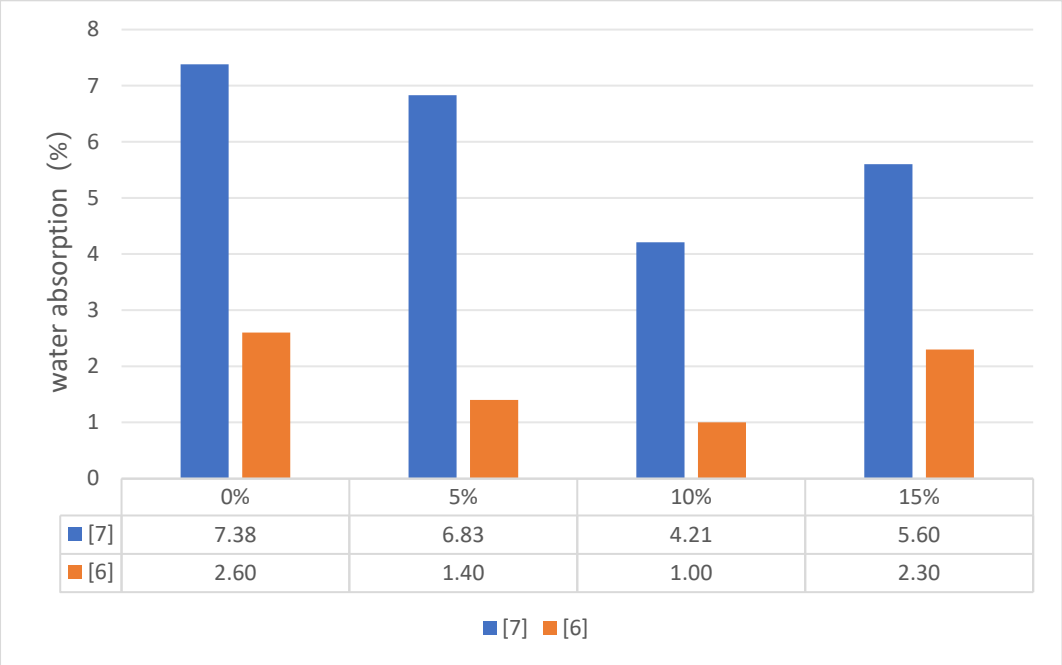

Figure 5.1. Water absorption rate

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6. Environmental and Economic Benefits of Bamboo Leaf Ash Concrete

6.1. Environmental benefits

The production of cement is one of the major sources of carbon dioxide emissions globally, accounting for approximately 5% of global greenhouse gas emissions. The carbon emissions during cement production primarily come from two sources: first, the decomposition of limestone ($CaCO_3 \rightarrow CaO + CO_2$), which generates a significant amount of carbon dioxide; second, the high-temperature calcination process in cement production, which requires large amounts of energy (such as coal, natural gas, etc.), and this process also produces greenhouse gases.

Bamboo leaf ash, as an environmentally friendly alternative material, can effectively reduce the amount of cement used in concrete, thereby reducing the demand for cement production. The carbon footprint of bamboo leaf ash is much lower than that of cement, and its production process is relatively simple, mainly involving the combustion and calcination of bamboo leaves to produce ash, which requires minimal energy consumption. Additionally, bamboo leaf ash itself is a pozzolanic material that can replace a portion of cement in concrete, reducing cement usage and thereby indirectly decreasing carbon emissions.

Research has shown that when bamboo leaf ash replaces 10% of cement, the carbon emissions of concrete decrease by approximately 5%. If bamboo leaf ash is applied on a large scale as a substitute for cement, this material can become an important means of mitigating carbon emissions in the construction industry. Especially in the context of global climate change and carbon reduction, bamboo leaf ash as a cement alternative not only meets the requirements of green buildings but also effectively alleviates the environmental burden of cement production.

Furthermore, the use of bamboo leaf ash helps reduce the accumulation of agricultural waste and the air pollution caused by its incineration. Bamboo leaves, as agricultural and forestry waste, are often burned or discarded if not effectively utilized. The use of bamboo leaf ash can convert this waste into a valuable resource, further reducing the environmental pressure associated with waste disposal.

6.2. Economic benefits

Bamboo leaf ash is a low-cost, readily available material that is significantly cheaper than cement. Therefore, using bamboo leaf ash as a partial replacement for cement can effectively reduce the production cost of concrete. This is especially beneficial in regions where bamboo leaf ash is abundant, as replacing cement with bamboo leaf ash not only lowers material costs but also reduces transportation and storage expenses. By incorporating bamboo leaf ash as a substitute material in concrete, energy consumption in cement production can be reduced, further lowering the overall production costs of construction materials.

The inclusion of bamboo leaf ash in concrete also helps improve its durability, particularly in terms of water resistance, freeze-thaw resistance, and resistance to chemical attacks. Bamboo leaf ash concrete exhibits good density and low water absorption, which contributes to enhanced impermeability, thereby improving the overall durability of the concrete. This means that in harsh environmental conditions, bamboo leaf ash concrete can have a longer service life, significantly reducing maintenance and repair costs for buildings. Therefore, bamboo leaf ash concrete holds promising prospects for widespread application in the construction industry.

7. Conclusion

Bamboo leaf ash, as a partial substitute for cement, offers significant improvements in mechanical properties and environmental benefits. Bamboo leaf ash can enhance the strength, toughness, and durability of concrete, and its use as a recycling material from agricultural waste

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contributes to environmental protection and sustainable development. Future research should further explore the optimal replacement ratio, mix design, and the long-term performance of bamboo leaf ash concrete under various environmental conditions, in order to achieve higher-performance green concrete.

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