Proceedings of the 3rd International Conference on Environmental Geoscience and Earth Ecology
DOI: 10.54254/2753-8818/2025.24577

Research Status of Biomass Ash in Ultra-High Performance Concrete

Gao Chen

College of Civil and Transportation Engineering, Hohai University,Nanjing, China
cg050917@outlook.com

Abstract. With the increasing accumulation of biomass ash (BA), the technical and environmental limitations associated with its disposal have become increasingly prominent, making the efficient utilization of BA an urgent global challenge. This paper reviews the current research on the application of various types of BA in ultra-high performance concrete (UHPC). Studies have shown that the differences in BA types can significantly affect the performance and microstructure of UHPC. When appropriately dosed, BA can markedly improve the macroscopic mechanical properties of UHPC, increasing compressive strength by approximately 0.3%–14.1%, flexural strength by 1.2%–12.0%, and elastic modulus by 0.2%–6.9%. However, excessive incorporation of BA may deteriorate the performance of UHPC. Moreover, the addition of BA can enhance the microstructure of UHPC by significantly reducing its porosity (by approximately 9.8%–57.9%). At the same time, BA demonstrates good potential for economic and environmental sustainability. Nevertheless, current research on the impact of BA on UHPC performance remains insufficiently clear. Future studies should focus on in-depth exploration and analysis of the underlying factors, especially through systematic investigations into durability.

Keywords: UHPC, biomass ash, performance, microstructure, ecological benefits

1. Introduction

Concrete is the most widely used building material in the world today, owing to its abundant raw materials, simple production process, and low cost. However, ordinary concrete suffers from significant drawbacks such as high self-weight and low tensile strength, making it inadequate for meeting the increasingly demanding performance requirements of modern large-scale and complex engineering projects. To address the future development trend of construction projects toward larger spans and scales, ultra-high performance concrete (UHPC) has been developed and applied in high-rise buildings, long-span bridges, nuclear power plants, subsea tunnels, and other infrastructure projects [1]. UHPC is a cement-based composite material composed of cement, silica fume (SF), fine aggregates, and other materials, characterized by ultra-high strength and high durability [2]. However, the production of UHPC requires a large amount of cementitious materials, which leads to high production costs and substantial CO_2 emissions, posing challenges to sustainable development. Consequently, the application of UHPC is somewhat limited [3].

DOI: 10.54254/2753-8818/2025.24577

Traditional mineral admixtures such as fly ash, ground granulated blast furnace slag, and metakaolin significantly improve the mechanical properties and microstructure of UHPC [4–6]. For instance, Li Yurong et al. [4] studied the use of fly ash microspheres in UHPC and found that when used at a dosage of 10%–25%, these microspheres—due to their spherical shape and pozzolanic activity—significantly enhanced the compressive strength of UHPC, particularly at later ages. The ball-bearing effect of the fly ash microspheres reduced water demand and improved the workability of UHPC. Chen Chao and Zhang Heng [5] examined the impact of high-titanium heavy slag sand on UHPC. Their results showed that UHPC made with rapidly cooled high-titanium slag sand had a dense microstructure and excellent resistance to chloride penetration, freeze-thaw cycles, and carbonation. When the fineness modulus of the slag sand was 2.6 and located in the median range of Zone II, UHPC exhibited optimal workability and mechanical performance. Mo Zongyun et al. [6] investigated the influence of metakaolin content on UHPC strength and microstructure. Their findings indicated that the compressive strength of UHPC increased with metakaolin content due to the pozzolanic reaction between metakaolin and $Ca(OH)_2$, which generated additional C-S-H gel and improved the microstructure's density. Thus, using mineral admixtures to partially replace cement or silica fume can optimize UHPC performance while conserving resources. However, as traditional thermal power plants are gradually being replaced by biomass power plants, the supply of conventional mineral admixtures is becoming increasingly strained, unable to meet the demands of the construction industry. Therefore, developing new, high-performance, and environmentally friendly alternative materials has become an urgent priority.

Biomass ash (BA) is the residual material left after the thermochemical conversion of biomass. It can be derived from agricultural biomass, forest biomass, livestock biomass, and municipal solid waste [7]. Compared with traditional admixtures, BA offers several advantages, including low energy consumption, abundant availability, low cost, and high reuse value [8]. Biomass ashes such as rice husk ash (RHA) and rice straw ash (RSA) have already been applied in UHPC. For example, Zhao et al. [9] used RHA and recycled construction sand to prepare environmentally friendly UHPC, which demonstrated not only excellent mechanical performance but also significantly improved environmental and economic benefits. Hakeem et al. [10] developed UHPC using a combination of RSA and nano eggshell powder and found that the material exhibited excellent mechanical and durability properties while also effectively mitigating environmental pollution. Therefore, incorporating BA into UHPC as a novel supplementary cementitious material is an effective solution to the aforementioned problems. Investigating the performance and application of BA in UHPC is both necessary and promising.

Based on this, the present paper systematically reviews the application of BA in UHPC, summarizes the effects of different types of BA on the mechanical properties and microstructure of UHPC, and evaluates their environmental and economic advantages. The aim is to provide a theoretical foundation and technical support for the future promotion and application of BA in UHPC production and to facilitate its broader adoption in the field.

2. Effects of Biomass Ash (BA) on UHPC properties

2.1. Workability

The incorporation of BA significantly influences the workability of UHPC, with its effect governed by factors such as type, dosage, and particle size. Zhuang Yizhou et al. [11] studied the impact of RHA dosage on UHPC flowability. Their results indicated that as the RHA content increased, more superplasticizer was required to maintain a slump flow of 180–200 mm, demonstrating that higher

DOI: 10.54254/2753-8818/2025.24577

RHA content reduced workability. Yang et al. [12] found that when 5% and 40% RHA were added, the flowability of the UHPC paste decreased by 14.2% and 30.3%, respectively, compared with the control group (0% RHA). This is attributed to the high specific surface area and strong water absorption capacity of RHA, which reduce the amount of free water in the mix. Additionally, as RHA particle size increased, the flowability of UHPC initially increased and then decreased. A moderate increase in particle size reduces water absorption, improving flowability, but excessively large particles weaken the filling effect and hinder water displacement, thereby lowering flowability. Huang et al. [13] partially replaced quartz powder with sugarcane bagasse ash (SCBA) and found that with increasing SCBA content, the flowability of the UHPC paste first increased and then decreased. The optimum flowability (220 mm) occurred at 40% SCBA content, while at 80%, the slump flow was similar to that of the SCBA-free mix. Similarly, de Sande et al. [14] reported that replacing fine aggregate with SCBA yielded comparable results. This is due to SCBA's relatively small specific surface area, which reduces interparticle friction and improves particle mobility. Lv et al. [15] found that municipal solid waste incineration fly ash (MSWIFA), after high-temperature treatment, reduced UHPC flowability. When 5%–20% MSWIFA was added, the slump flow decreased by 2.2%–8.3%. This was because MSWIFA particles are porous and angular with a high specific surface area, which increases interparticle friction and absorbs mixing water, thereby reducing flowability.

2.2. Setting time

Different types of BA affect UHPC setting time differently. Zha et al. [16] investigated the combined use of blast furnace slag and RHA and found that increasing RHA content shortened the initial setting time but extended the final setting time. Yang et al. [17] observed similar trends when combining basic oxygen furnace slag and RHA. This was due to RHA's early-stage water absorption, which lowered the water-to-binder ratio and accelerated loss of plasticity. However, due to RHA's low pozzolanic activity and dilution effect from cement replacement, the formation of hydration products was delayed. In contrast, Wu et al. [18] found that SCBA slightly prolonged the initial setting time but significantly delayed the final setting time. Compared to the control group (0% SCBA), the final setting times of UHPC with 20%, 40%, and 60% SCBA increased by 79, 83, and 99 minutes, respectively. This was because SCBA reduced the content of tricalcium aluminate (C_3A), thereby suppressing hydration reactions and delaying setting and hardening. On the other hand, Lv et al. [15] reported that high-temperature-treated MSWIFA significantly shortened UHPC setting times. Compared with the control (0% MSWIFA), the initial and final setting times of UHPC with 5%–20% MSWIFA were shortened by 13.2%–40.1% and 22.4%–57.0%, respectively. This was attributed to chloride ions in MSWIFA accelerating the precipitation of $Ca(OH)_2$, thereby speeding up setting and hardening.

2.3. Compressive strength

The addition of BA can enhance the compressive strength of UHPC. Hu Jinlong [19] studied the effect of straw ash (SA) on UHPC compressive strength and found that incorporating 10% SA improved the compressive strength by 8.5%, 3.6%, 3.3%, and 2.2% at 7, 28, 60, and 120 days, respectively. However, a 20% replacement rate reduced strength. This is because a moderate amount of SA promotes hydration and provides a filling effect, while excessive SA dilutes the cement content, reducing the amount of hydration products and compromising microstructural compactness. Nguyen et al. [20] found that incorporating RHA effectively enhanced UHPC compressive strength, with 20% RHA increasing the 28-day and 91-day strengths by 7.3% and 6.9%, respectively. Yang et al. [12] reported similar findings (see Fig. 1). They attributed the improvement to RHA's filling and internal curing effects, which enhance strength development. Additionally, finer RHA particles provided a greater surface area, absorbing more water during early hydration, lowering the water–cement ratio, and promoting more hydration products and a denser microstructure.

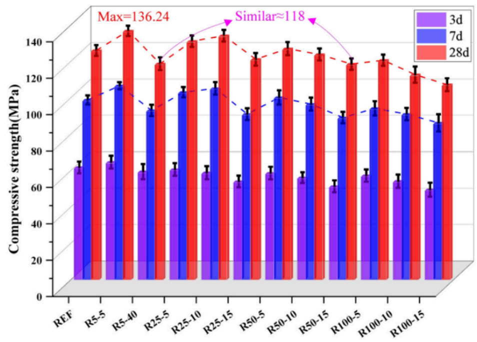

Figure 1. The influence of RHA on the compressive strength of UHPC [12]

Amin et al. [21] found that moderate RSA content (≤40%) increased UHPC compressive strength. Hakeem et al. [10] reported that 10%–30% RSA raised the 28- and 91-day compressive strength by 10.1%–14.1% and 11.6%–16.2%, respectively. Similarly, Hakeem et al. [22] observed that 20%–40% SLA increased compressive strength by 2.7%–12.2%, while 50% SLA reduced it by 4.7%. Wu et al. [18] noted that SCBA did not significantly improve 28-day compressive strength, but 91-day strength was significantly higher than the control, indicating excellent long-term strength development. These enhancements are due to the pozzolanic reactivity of RSA, SLA, and SCBA, which react with $Ca(OH)_2$ to form additional C-S-H gel. However, excessive amounts produce dilution effects, reducing hydration products and compressive strength. Lv et al. [15] showed that incorporating 5%–20% treated MSWIFA improved 28-day compressive strength by 0.3%–5.4%, owing to the synergistic effect of its pozzolanic and filler properties, which enhance density and hydration.

2.4. Flexural strength

BA also enhances the flexural strength of UHPC. Yang et al. [12] found that incorporating RHA significantly improved the flexural strength of UHPC. At a 5% replacement rate, the 28-day flexural strength increased by 9.8% compared to the control group (0% RHA). However, when the dosage was increased to 40%, the flexural strength decreased. Similar results were reported by Huang et al. [23]. RHA promotes the formation of hydration products, improves the fiber–matrix interfacial transition zone, and fills pore structures, thereby increasing flexural strength. Nevertheless, excessive RHA tends to absorb large amounts of free water, hindering hydration and reducing the amount of hydration products, which in turn lowers flexural strength. Likewise, Hakeem [10] and Amin [21] investigated the strengthening effects of RSA and found that the 28-day flexural strength of UHPC improved by 1.2%–12.0% when RSA was added at a dosage of 10%–40%. This enhancement was attributed to the pozzolanic reaction of RSA, which promotes hydration. Shaban et al. [24] conducted a comparative study on SCBA and SLA. Their results showed that incorporating 10%, 20%, and 30% SCBA increased UHPC flexural strength by 5.6%, 11.6%, and 6.0%, respectively. For SLA, the corresponding improvements were 4.0%, 10.0%, and 4.3%. These effects were mainly due to the combined pozzolanic and filling effects of SCBA and SLA, which

DOI: 10.54254/2753-8818/2025.24577

densified the internal structure and enhanced flexural strength. However, when the substitution rate reached 50%, flexural strength declined.

2.5. Elastic modulus

The addition of BA also improves the elastic modulus of UHPC. Alyami et al. [25] reported that adding 10%, 20%, 30%, and 40% RHA increased the 28-day elastic modulus by 3.7%, 6.9%, 4.0%, and 1.6%, respectively. However, a 50% replacement led to a 0.7% reduction. Wang Xiaolong [26] obtained similar results, attributing the improvement to RHA's pozzolanic and filling effects, which refine the pore structure and enhance UHPC density. Similarly, Hakeem et al. [10] reported that 10%, 20%, and 30% RSA increased the 28-day elastic modulus by 4.8%, 6.8%, and 4.3%, respectively. Amin et al. [21] found that with RSA content ranging from 10% to 50%, the elastic modulus improved by 0.2%–7.0%, with the enhancement mechanism resembling that of RHA—i.e., densification due to the pozzolanic reaction of SiO_2. Alyami et al. [25] also found that incorporating 10%, 20%, 30%, and 40% SLA increased the elastic modulus by 2.8%, 5.6%, 3.1%, and 1.0%, respectively. Shaban et al. [24] compared the effects of SLA and SCBA: for 10%–40% SLA, the modulus increased by 2.0%, 5.0%, 2.5%, and 0.2%, whereas SCBA improved the modulus by 3.0%, 6.0%, 3.4%, and 0.7%, respectively.

In summary, the enhancement mechanisms of BA on UHPC mechanical properties mainly include the synergistic effects of pozzolanic reaction, particle filling, and internal curing. However, these effects vary across BA types—for instance, RHA, RSA, and SLA significantly improve 28-day compressive strength, while SCBA's effect is less pronounced. Therefore, in practical engineering applications, the selection of BA type and dosage should align with the desired performance and material characteristics to optimize the balance between performance and sustainability.

Table 1. The influence of different types of BA on the mechanical properties of UHPC (with Increasing Substitution Rate)

BA	Flowability	Setting time	Compressive strength	Flexural strength	Elastic modulus
SA	—	—	first increased and then decreased	—	—
RHA	first increased and then decreased	the initial setting time decreased, the final setting time increased	increased	increased	increased
RSA	—	—	increased	increased	increased
SCBA	first increased and then decreased	the initial setting time increased slightly, the final setting time increased significantly	first increased and then decreased	first increased and then decreased	first increased and then decreased
SLA	—	—	first increased and then decreased	first increased and then decreased	first increased and then decreased
MSWIFA	decreased	decreased	increased	—	—

DOI: 10.54254/2753-8818/2025.24577

2.6. Shrinkage performance

Various types of BA exhibit notable effects in controlling both drying shrinkage and autogenous shrinkage in UHPC. Hu Jinlong [19] found that incorporating 10% and 20% SA reduced the 28-day total shrinkage of UHPC by 28.0% and 31.7%, and autogenous shrinkage by 29.7% and 39.0%, respectively. This is because replacing cement with SA reduces the heat of hydration and effectively controls early-age volume deformation. Ye Guang and Nguyen [27] examined the effects of RHA dosage and particle size on autogenous shrinkage. Results showed that higher RHA content significantly reduced autogenous shrinkage. This was attributed to RHA's pozzolanic effect, which improved compactness and deformation resistance, and its internal curing effect, which released water to mitigate shrinkage. Furthermore, larger RHA particles (5.6–9.0 μm) exhibited higher water absorption and better internal curing, further suppressing autogenous shrinkage. Wu et al. [18] investigated the effect of SCBA on autogenous shrinkage. When SCBA was substituted at 20%, 40%, and 60%, autogenous shrinkage was reduced by 19.2%, 24.5%, and 30.3%, respectively. The underlying mechanisms included reduced cement content (and thus lower hydration heat) and the internal curing effect maintaining internal humidity.

Regarding drying shrinkage, Hu Jinlong [19] found that at a 10% SA replacement rate, 28-day drying shrinkage was reduced by 18.5%, while a 20% replacement increased it by 6.4%, which deviated from the trend observed in autogenous shrinkage. Hakeem et al. [10] reported that adding RSA increased drying shrinkage. At 10%, 20%, and 30% RSA, drying shrinkage increased by 2.7%–7.3%, 6.0%–16.7%, and 12.6%–25.0%, respectively. This was due to the formation of C-S-H gel from RSA's pozzolanic reaction with $Ca(OH)_2$, which, while densifying the structure, led to greater chemical shrinkage.

3. Effects of Biomass Ash (BA) on the microstructure of UHPC

The incorporation of biomass ash (BA) significantly improves the microstructure of ultra-high performance concrete (UHPC). Yang et al. [12], using scanning electron microscopy (SEM), observed that adding 5% rice husk ash (RHA) reduced the total porosity of UHPC by 27.8% compared with the control group (0% RHA). This indicates that an appropriate amount of RHA can effectively reduce porosity, enhance density, and improve the pore structure. However, when RHA particles are too large, incomplete local hydration may occur, which could negatively affect the compactness of the microstructure. Alyami et al. [25] further reported that at a 20% replacement rate, the content of calcium–silicate–hydrate (C-S-H) gel in UHPC increased, making the microstructure denser. Amin et al. [21] found that adding rice straw ash (RSA) effectively filled internal voids, thereby improving the microstructure of UHPC. Hakeem et al. [10] reached similar conclusions. Additionally, Hakeem et al. [22] found that incorporating 20% sugarcane leaf ash (SLA) led to a denser UHPC matrix with fewer internal pores, which enhanced the microstructure. This improvement was attributed to the combined pozzolanic and filling effects of RSA and SLA.

Wu et al. [18] discovered that replacing 20% of the binder with sugarcane bagasse ash (SCBA) reduced the total porosity of UHPC by 12.2% compared to the control (0% SCBA), as shown in Fig. 2. Huang et al. [13] also pointed out that SCBA helps refine pore size distribution and reduce total porosity. In fact, when the SCBA replacement rate reached 60%, porosity in all pore size ranges was minimized. Lv et al. [15] similarly found that municipal solid waste incineration fly ash (MSWIFA), after high-temperature treatment, contributed to pore structure refinement. The total porosity of UHPC containing 5%, 10%, 15%, and 20% MSWIFA decreased by 57.9%, 9.8%, 49.4%, and

12.7%, respectively. Additionally, MSWIFA reduced the proportion of harmful pores and increased the proportion of harmless pores, thereby optimizing the pore size distribution.

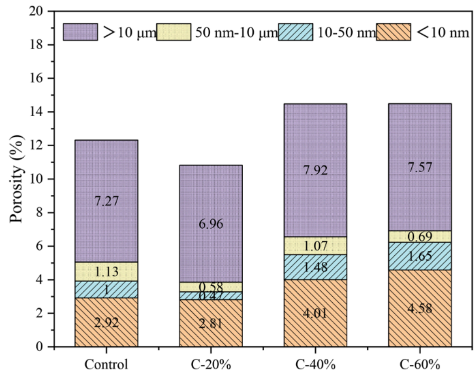

Figure 2. The influence of SCBA on the porosity of UHPC [17]

4. Environmental and economic benefits of Biomass Ash (BA)

The application of biomass ash (BA) in ultra-high performance concrete (UHPC) provides significant environmental and economic advantages. Yang et al. [12], using life cycle assessment (LCA), analyzed the environmental benefits of rice husk ash (RHA) and found that incorporating 40% RHA—without compromising UHPC strength and durability—reduced non-renewable energy consumption, renewable energy consumption, global warming potential, eutrophication potential, and acidification potential by 3.0%, 10.3%, 20.9%, 29.0%, and 3.9%, respectively. Zhao et al. [9] further pointed out that compared to silica fume (SF), RHA significantly reduces energy consumption during production and emissions of pollutants. Thus, RHA demonstrates strong synergetic benefits in both environmental and economic dimensions. Huang et al. [13] used LCA to evaluate the environmental impact of different SCBA (sugarcane bagasse ash) contents. They found that at an 80% replacement rate, UHPC's acidification potential, global warming potential, abiotic depletion potential, and fine particulate matter generation were reduced by 19.8%, 17.5%, 10.7%, and 8.8%, respectively—representing the most favorable environmental performance. Li et al. [28] supplemented this view by noting that although SCBA's CO_2 emissions are higher than those of fly ash, SF, and RHA, they are still 7.5 times lower than those of cement. In terms of cost, SCBA is significantly cheaper than cement, SF, and RHA, reflecting its high economic efficiency. Therefore, the use of SCBA is both cost-effective and environmentally sustainable. In addition, Mao et al. [29] studied the application of high-temperature-treated municipal solid waste incineration fly ash (MSWIFA) in UHPC. Their results showed that increasing MSWIFA content from 10% to 40% led to reductions in total carbon emissions, total energy consumption, and overall production cost by 6.9%–27.4%, 6.5%–26.1%, and 1.4%–5.7%, respectively. These findings underscore the environmental and economic viability of MSWIFA in UHPC production.

5. Conclusion

This paper systematically reviews the progress in the application of biomass ash (BA) in ultra-high performance concrete (UHPC), summarizing and analyzing its effects on workability, mechanical properties, shrinkage behavior, microstructure, and environmental and economic performance. The main conclusions are as follows:

DOI: 10.54254/2753-8818/2025.24577

(1) Workability and Setting Time: Under suitable dosage and particle size conditions, certain types of BA (e.g., RHA and SCBA) can improve the flowability of UHPC and enhance its workability. However, some types of BA (e.g., MSWIFA) may reduce flowability due to their particle characteristics. Likewise, different types of BA influence the setting time of UHPC in varying ways—RHA and SCBA tend to prolong the final setting time, whereas MSWIFA significantly accelerates the setting process.

(2) Mechanical Properties and Shrinkage: BA can significantly enhance the compressive strength, flexural strength, and elastic modulus of UHPC, demonstrating good reinforcing potential. Different types of BA exhibit varying degrees of effectiveness, with moderate dosages (usually ≤30%) being most favorable. BA also effectively mitigates autogenous shrinkage due to its internal curing effect and ability to regulate hydration heat. However, its impact on drying shrinkage differs among BA types.

(3) Microstructural Improvement: The incorporation of BA markedly optimizes the microstructure of UHPC by reducing total porosity, refining pore size distribution, and strengthening interfacial bonding. These changes contribute to improved density and long-term performance.

(4) Environmental and Economic Sustainability: From ecological and economic perspectives, replacing traditional cementitious materials with BA can reduce carbon emissions, conserve energy, and lower production costs. This presents a viable pathway toward greener and more sustainable concrete development.

6. Outlook

(1) The physicochemical properties of different types of biomass ash (BA) vary significantly. There is no unified consensus yet on the influence patterns of its dosage, particle size, and treatment conditions on the performance of ultra-high-performance concrete (UHPC). Future work should undertake systematic comparative studies to determine the optimal dosage ranges and the synergistic enhancement mechanisms.

(2) Current research on the durability performance of UHPC containing BA—such as resistance to carbonation, chloride ion penetration, and sulfate attack—is still relatively limited. It is recommended to systematically investigate the evolution patterns and mechanisms of durability under long-term service environments to fill relevant research gaps.

(3) To promote the standardization and engineering application of BA in the UHPC field, further efforts should be made to elucidate the sources of BA activity, microstructural regulation mechanisms, and performance evolution pathways, thereby establishing a controllable system from material design to performance prediction.

Reference

[1] Chen B C, Ji T, Huang Q W, et al. Review of Research on Ultra-high Performance Concrete [J]. Journal of Architecture and Civil Engineering, 2014, 31(03): 1-24.
[2] Wang H. Review of Research on Ultra-high Performance Concrete(UHPC) [J]. China Concrete and Cement Products, 2022, (04): 25-28.
[3] Zou H J, Zhu Y W, Mao L, et al. Research on the application of mineral admixture in UHPC [J]. Construction Machinery, 2023, (09): 139-145.
[4] Li Y R, Xia C L, Zhang Y C, et al. Application of Fly Ash Microsphere in Ultra-High Performance Concrete(UHPC) [J]. China Concrete, 2020, (01): 74-77.
[5] Chen C, Zhang H. Effect of High Titanium Heavy Slag Sand on the Properties of Ultra-high Performance Concrete(UHPC) [J]. China Concrete and Cement Products, 2023, (01): 74-78+83.

[6] Mo Z Y, Bai L G, Wang D G, et al. Effect of Metakaolin on the Properties of Ultra High Performance Concrete [J]. Non-Metallic Mines, 2018, 41(06): 30-32.
[7] Chen J, Li S, Chen X X. Characteristics and Comprehensive Utilization of Biomass Ash [J]. Scientific and Technological Innovation, 2020, (02): 50-51.
[8] Ma B C, Liang J, Weng Y L. Research Review of Biomass Ash as Concrete Admixture [J]. Journal of China & Foreign Highway, 2024, 44(05): 97-107.
[9] Zhao S, Yang Y, Liu J, et al. Rice husk ash and recycled sand as synergistic substitutes in ultra-high performance concrete: Microstructural, mechanical performance, and eco-economic analysis [J]. Construction and Building Materials, 2024, 453: 138945.
[10] Hakeem I Y, Amin M, Agwa I S, et al. Ultra-high-performance concrete properties containing rice straw ash and nano eggshell powder [J]. Case Studies in Construction Materials, 2023, 19: e02291.
[11] Zhuang Y Z, Zheng H B, Ji T, et al. Experimental Research of Rice Husk Ash Replacing Silica Fume on Performance Effects of Ultra-high Performance Concrete [J]. China Concrete and Cement Products, 2012, (06): 10-14.
[12] Yang Y P, Deng Y G, Chen L S. Properties of high-volume rice husk ash UHPC with various fineness [J]. Construction and Building Materials, 2025, 458: 139614.
[13] Huang P, Huang B, Li J, et al. Application of sugar cane bagasse ash as filler in ultra-high performance concrete [J]. Journal of Building Engineering, 2023, 71: 106447.
[14] de Sande V T, Sadique M, Pineda P, et al. Potential use of sugar cane bagasse ash as sand replacement for durable concrete [J]. Journal of Building Engineering, 2021, 39: 102277.
[15] Lv Y, Yang L, Wang J, et al. Performance of ultra-high-performance concrete incorporating municipal solid waste incineration fly ash [J]. Case Studies in Construction Materials, 2022, 17: e01155.
[16] Zha J, Li J H, Jiao Y P, et al. Investigation on Basic Properties of Rice husk ash–blast furnace slag Composite Binder [J]. Advanced Materials Research, 2014, 919: 2071-2075.
[17] Yang W, Xue Y, Wu S, et al. Performance investigation and environmental application of basic oxygen furnace slag–Rice husk ash based composite cementitious materials [J]. Construction and Building Materials, 2016, 123: 493-500.
[18] Wu N, Ji T, Huang P, et al. Use of sugar cane bagasse ash in ultra-high performance concrete (UHPC) as cement replacement [J]. Construction and Building materials, 2022, 317: 125881.
[19] Hu J L. Effect of Straw Ash on Compressive Strengths and Shrinkage of UHPC [J]. Journal of Municipal Technology, 2023, 41(09): 55-58+73.
[20] Nguyen Van Tuan, Guang Ye, Klaas van Breugel, Oguzhan Copuroglu. Hydration and microstructure of ultra high performance concrete incorporating rice husk ash [J]. Cement and Concrete Research, 2011, 41: 1104－1111
[21] Amin M, Tayeh B A, Kandil M A, et al. RETRACTED: Effect of rice straw ash and palm leaf ash on the properties of ultrahigh-performance concrete [J]. Case Studies in Construction Materials, 2022, 17: e01266.
[22] Hakeem I Y, Amin M, Agwa I S, et al. Effect of using sugarcane leaf ash and granite dust as partial replacements for cement on characteristics of ultra-high performance concrete [J]. Case Studies in Construction Materials, 2023, 19: e02266.
[23] Huang H, Gao X, Wang H, et al. Influence of rice husk ash on strength and permeability of ultra-high performance concrete [J]. Construction and Building Materials, 2017, 149: 621-628
[24] Shaban W M, Heniegal A M, Amin M, et al. Effect of agricultural wastes as sugar beet ash, sugarcane leaf ash, and sugarcane bagasse ash on UHPC properties [J]. Journal of Building Engineering, 2024, 98: 111359.
[25] Alyami M, Hakeem I Y, Amin M, et al. Effect of agricultural olive, rice husk and sugarcane leaf waste ashes on sustainable ultra-high-performance concrete [J]. Journal of Building Engineering, 2023, 72: 106689.
[26] Wang X L. Influence of Rice Husk Ash and Assorted Fibers on Ultra-High Performance Concrete [J]. Synthetic Fiber in China, 2022, 51(11): 69-74.
[27] Ye G, V.T.NGUYEN, Mitigation of Autogenous Shrinkage of Ultra-High Performance Concrete by Rice Husk Ash [J]. Journal of the Chinese Ceramic Society, 2012, 40(02): 212-216.
[28] Li Y, Chai J, Wang R, et al. Utilization of sugarcane bagasse ash (SCBA) in construction technology: A state-of-the-art review [J]. Journal of Building Engineering, 2022, 56: 104774.
[29] Mao J, Zhou A, Liang Y, et al. Innovative dual-benefit recycling and sustainable management of municipal solid waste incineration fly ash via ultra-high performance concrete [J]. Science of the Total Environment, 2024, 957: 177852.