

## Hardened and Durability Parameters of Concrete Incorporating Industrial By-Products and Agricultural Wastes: A Review

Gurpreet Singh Sidhu

Department of Civil Engineering, Punjabi university, Patiala-147002, INDIA  
(gurpreet.sidhu69@gmail.com)

### Abstract

Notably, concrete is the commonly utilized material in construction purpose, yet its production entails the consumption of substantial quantities of cement and natural aggregates. Cement production adds a large share of carbon dioxide emissions, and extracting aggregates harms the environment. Incorporating industrial by products and agricultural residues into concrete has become a pivotal sustainable construction strategy. On top of that, this review examines the hardened and durability properties of concrete adding fly ash, ground granulated blast furnace slag, silica fume, waste glass powder, recycled aggregates, rice husk ash, sugarcane bagasse ash, palm oil fuel ash, coconut shell, and other agricultural residues. On top of that, studies show that properly treated waste can improve compressive strength, tensile strength, flexural strength, chloride resistance, sulphate resistance, water absorption, sorptivity, and microstructure. However, using too much replacement often weakens the material because of dilution, poor particle packing, high porosity, or weak zones where materials meet, in real world settings. Many research finding revealed that optimum replacement levels vary by material, with 10-20% for rice husk ash, 5-15% for sugarcane bagasse ash, 10-30% for fly ash, 20-50% for GGBS, 5-15% for silica fume, and 10-20% for waste glass powder. On top of that, recycled aggregates and lightweight agricultural aggregates may diminish compressive strength, yet they can still be employed effectively when combined with pozzolanic materials or through judicious adjustments to mix design. Overall, waste-based concrete can attain satisfactory mechanical performance and durability, provided that material quality, fineness, calcination temperature, replacement level, curing regimen, and water binder ratio are meticulously controlled.

**Keywords:** Fly ash, rice husk ash, fly ash, slag, sugarcane bagasse ash, durability, compressive strength, sustainable concrete.

### 1. Introduction

Concrete production relies predominantly on ordinary Portland cement, natural sand, and coarse aggregates. Escalating infrastructure demand intensifies environmental burdens via cement related carbon emissions, quarrying, and disposal waste from industry and agricultural. Consequently, researchers have investigated the utilization of waste by products into concrete employing them as supplementary cementitious materials, aggregate replacements, fillers, and fibrous reinforcements to valorize residues, mitigate environmental impacts, and enhance material performance. By virtue of their pozzolanic activity and filler effect, researchers frequently investigate industry wastes such as FA, GGBFS, SF, CBA, RCA, and waste glass powder. Owing to the presence of reactive silica and their potential to function as lightweight aggregates, focus has also been pointed toward agricultural wastes such as RCA, SBA, POFA, coconut shell, corn cob ash, and bamboo leaf ash.

The results of waste-based concrete depend strongly on the physical and chemical nature of the waste material, and those properties determine how well the concrete performs. Amorphous silica rich materials, notably rice husk ash and silica fume, consume hydration derived calcium hydroxide to produce excess calcium silicate hydrate gel. This enhances the density of the cement matrix and reduces permeability. Long term strength and durability are improved by fly ash because of its slow pozzolanic activity, while GGBS contributes through latent hydraulic reactions. In contrast, porosity and water absorption are frequently elevated by recycled and organic agricultural aggregates, a change that may impair strength unless mix designers implement appropriate modifications.

### 2. Methodology of the Review

On top of that, the review focuses on strength properties and durability parameters of mixture that incorporates waste by products and agricultural wastes. The main hardened properties reviewed include compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, density, and ultrasonic pulse velocity. Durability parameters are water absorption, sorptivity, chloride penetration, sulphate resistance, acid resistance, carbonation resistance, drying shrinkage, freeze–thaw resistance, and permeability.

The reviewed materials were in two parts:

Industrial waste by-products: FA, GGBS, SF, waste glass powder, coal bottom ash, recycled concrete aggregate.

Agricultural wastes: rice husk ash, sugarcane bagasse ash, palm oil fuel ash, coconut shell, corn cob ash.

### 3. Industrial Waste By-Products in Concrete

#### 3.1 Fly Ash

Fly ash is common material added to concrete to replace part of the cement in everyday construction. It is produced from coal combustion and contains silica, alumina, and iron oxides. Fly ash enhances the workability because of its spherical particle shape. However, early-age strength may decrease because fly ash reaction is slow than cement. At later ages, strength often improves due to pore refinement. [1,2]

From the findings, fly ash replacement between 15% and 30% often improves long-term compressive strength and durability. It reduces heat of hydration, permeability, chloride penetration, and sulphate attack. Fly ash-based concrete is particularly useful in mass concrete and marine structures because it reduces cracking and improves resistance to aggressive ions. However, high-volume FA based concrete needs longer curing and careful quality control [3,4,5].

#### 3.2 Ground Granulated Blast-Furnace Slag

GGBS is a by-product of the iron industry. It has latent hydraulic properties and reaction with calcium hydroxide in the presence of water. Researches have shown that GGBS improves long-term strength, chloride resistance, sulphate resistance, and pore structure [7,8]. A comprehensive review reported that GGBS improves durability, density, permeability resistance, acid resistance, carbonation behavior, and shrinkage performance.

Optimum replacement levels vary depending on cement type, curing, and exposure conditions. In normal concrete, 30–50% GGBS replacement often gives good long-term performance. In high-performance concrete, finely ground slag can improve early strength and reduce permeability [9]. Teng et al. reported that ultra-fine GGBS concrete achieved higher early strength, lower permeability, and improved durability even at early curing ages [10, 11].

#### 3.3 Silica Fume

Silica fume is an ultra-fine waste by-product from silicon and ferrosilicon alloy production. It contains very high amorphous silica [12].

Due to its tiny particles, silica fume fills micro voids and improves the surface interaction zone between aggregate and paste. It increases compressive strength, tensile strength, FS, and durability. Replacement levels of 5–15% are commonly reported as effective [13,14].

Silica fume concrete shows excellent resistance to chloride penetration and water absorption. However, because silica fume (SF) has a very high surface area, it increases water demand [15]. Therefore, superplasticizers are usually required to maintain workability [16,17].

#### **3.4 Waste Glass Powder (WSP)**

Waste glass powder can behave as a pozzolanic substance when finely ground. It contains high silica content and can add concrete strength and durability at proper replacement levels. Empirical investigations indicate that partial substitution of 5 -20% of cement incorporating finely ground glass powder in cementitious materials can enhance compressive strength and reduce water absorption. However, large glass particles can cause an alkali silica reaction, so fine grinding is necessary in practice [18,19].

A study found that replacing 5% waste glass powder did not reduce compressive or tensile strength in real world settings. Careful particle size control is required for higher replacement levels, while low replacement levels pose less risk [19].

#### **3.5 Recycled Concrete Aggregate (RCA)**

Recycled concrete aggregate is obtained from demolished concrete. It decreases the need for natural aggregate and helps manage construction waste. However, recycled aggregate usually contains old mortar attached to natural aggregate. This increases water absorption and porosity and may reduce strength [20].

Research shows that partly added coarse aggregate with recycled aggregate often reduces compressive strength; the effect is stronger at high replacement levels. However, good quality recycled aggregate can replace 30 -50% of fresh aggregate in mixtures with only a small decrease in strength [21,22]. In particular, concrete made with 100% recycled aggregate can meet strength and durability requirements for some applications when aggregate quality and mix design are properly controlled [23].

### **4. Agricultural Waste Materials in Concrete**

#### **4.1 Rice Husk Ash (RHA)**

Rice husk ash is obtained by burning rice husk, an agricultural waste from rice milling. It contains high silica, especially when burned under controlled temperature. Properly burned and finely ground RHA acts as a pozzolanic ash. It improves compressive strength, reduces permeability, and enhances durability.

Many studies report optimum cement replacement between 10% and 20%. Ramasamy found that using RHA at suitable replacement levels improved compressive strength and durability in real world settings. The study investigated compressive, split-tensile and flexural strengths, as well as durability, for RHA cement replacement values of 0%,25% in 5% increments [24].

#### **4.2 Sugarcane Bagasse Ash (SBA)**

Sugarcane bagasse ash comes from burning sugarcane bagasse, a waste of the sugar industry. It contains silica and alumina and can behave as a pozzolanic material if properly processed. Studies show that 5–15% SCBA replacement can improve strength and durability. Farrant et al. studied sugarcane bagasse ash with silica fume in binary and ternary blended cement concrete, and they evaluated its mechanical and durability performance [25].

Moderate SCBA content improves pore structure and reduces water absorption. On the other hand, untreated SCBA may contain unburned carbon and coarse particles, which reduce strength. Therefore, grinding and controlled burning are important.

#### **4.3 Palm Oil Fuel Ash (PoFA)**

Palm oil fuel ash is generated from palm oil mills. It is rich in silica utilized as a supplementary cementitious material. result shows that POFA improves long-term strength and durability when finely ground. It can reduce chloride penetration, water absorption, and sulphate attack. Because of a slower pozzolanic reaction, early strength may be decreases by high replacement levels [26].

A state-of-the-art review of palm oil fuel ash reported its effects on workability, compressive strength, splitting tensile strength, durability, sustainability, and microstructure in real world settings. Another 2022 study tested high volume POFA in self-compacting concrete to cut cement use without losing performance [27].

#### **4.4 Coconut Shell**

Coconut shell is used mainly as a lightweight coarse aggregate. It reduces concrete density and can produce lightweight concrete. Coconut shell concrete usually has lower compressive strength than normal aggregate concrete, because coconut shells are less stiff and absorb more water. It is suitable for non-structural and lightweight applications when strength requirements are moderate.

#### **4.5 Corn Cob Ash and Bamboo Leaf Ash**

On top of that, corn cob ash and bamboo leaf ash are agricultural ashes containing silica and alumina. They can partially replace cement at low levels. Studies generally show that replacement levels around 5–10% may improve or maintain strength, while higher levels reduce strength. On top of that, these materials need more study because their chemical composition changes with burning temperature, grinding, and source.

### **5. Hardened Properties**

#### **5.1 Compressive Strength (CS)**

CS is the most commonly studied hardened property. Waste by-products with pozzolanic activity usually improve later-age strength. Silica fume, RHA, GGBS, fly ash, POFA, and SCBA can enhances compressive parameters by producing secondary C-S-H gel. However, early-age strength may decrease with fly ash, GGBS, POFA, and SCBA because their reaction is slower than cement hydration [3,7].

The best results are usually obtained at moderate replacement levels. For RHA, 10–15% is often optimum. For SCBA, 5–10% is commonly effective. For fly ash, 20–30% is practical. For GGBS, 30–50% can perform well. For silica fume, 5–10% gives high strength improvement. For waste glass powder, 10–20% may be good if the powder is very fine [26].

Recycled aggregate concrete often shows reduced compressive strength because of old mortar and higher porosity. However, combining recycled aggregate with fly ash, silica fume, or RHA improves the surface transition zone and reduces strength loss. Research on recycled aggregate concrete and pozzolans found that combining fly ash, silica fume, and rice husk ash produced high strength recycled aggregate concrete in real world settings [18].

### 5.2 Splitting Tensile Strength

The trend similar to compressive strength. Pozzolanic materials enhance tensile strength by densifying the mixture and reinforcing the interfacial bond between paste and aggregate, in real world settings. Silica fume is especially effective because it improves the interfacial transition zone, the thin weaker layer between cement paste and aggregate, making that zone denser and strengthening the bond. Additionally, RHA and SCBA improve tensile strength at moderate replacement levels.

On top of that, lightweight agricultural aggregates such as coconut shell may attenuate tensile strength owing to their reduced stiffness. Recycled aggregate can also reduce tensile strength in real world settings unless it is treated or blended with supplementary cementitious materials [19].

### 5.3 Flexural Strength (FS)

FS is important for pavements, slabs, and beams. SF, (RHA), (GGBS), and waste glass powder can enhance flexural strength when incorporated at appropriate proportions in practical applications. The improvement is linked with better paste–aggregate bonding and reduced microcracking. SCBA and POFA can also increase the bending (flexural) strength of concrete when tested at later ages [12].

On the other hand, high replacement levels may reduce flexural strength because of weaker paste and higher porosity. That said, agricultural aggregates typically diminish flexural strength unless reinforced with fibres or supplemented by pozzolanic binders.

### 5.4 Modulus of Elasticity (MoE)

The MoE depends on aggregate stiffness and paste quality. Pozzolanic materials may slightly improve modulus by improving matrix density. However, recycled aggregate and coconut shell usually reduce the modulus; they are more porous and less stiff than natural aggregate. Therefore, such concretes may show higher deformation under load.

## 6. Durability Properties

### 6.1 Water Absorption and Sorptivity

Water absorption and sorptivity are important indicators of pore structure. Pozzolanic materials generally reduce water absorption by filling pores and forming extra hydration products that refine the pore structure, making the material denser and less able to absorb water. RHA, silica fume, GGBS, fly ash, SCBA, and POFA attenuate capillary porosity when incorporated at their optimum replacement levels in real world applications.

Nonetheless, the inclusion of recycled aggregate, coconut shell, and suboptimally combusted agricultural ash can increase water absorption in real world settings. This effect is attributable to elevated porosity, deficient aggregate integrity, and an incomplete pozzolanic reaction, which together compromise the composite microstructure and reduce mechanical performance [34,35,36].

### 6.2 Chloride Penetration

Chloride ingress critically compromises reinforced concrete in marine or de icing environments. Notably, GGBS, FA, SF, and RHA exhibit pronounced efficacy in attenuating chloride penetration. They refine pore structure and improve binding capacity. GGBS concrete is widely reported to exhibit pronounced chloride resistance, as the slag refines the microstructure and thereby reduces permeability [27,28,29].

### 6.3 Sulphate Resistance

Sulphate attack causes expansion, cracking, and loss of strength. Fly ash, GGBS, and silica fume improve sulphate resistance by reducing calcium hydroxide and permeability. GGBS is especially useful in sulphate environments because it lowers the amount of reactive aluminates and makes the cement matrix denser, thereby enhancing resistance to sulphate attack [30].

### 6.4 Acid Resistance

Concrete is usually vulnerable to acid attack in everyday situations because acids dissolve its calcium based hydration products. Pozzolanic materials improve acid resistance by reducing calcium hydroxide and densifying the matrix. Waste glass powder, SCBA, and POFA can improve residual strength under acidic exposure at optimum levels. However, no cement concrete is fully acid-proof [18].

### 6.5 Carbonation Resistance

Carbonation resistance depends on permeability and alkalinity. Pozzolanic materials reduce permeability but also consume calcium hydroxide, which may lower alkalinity. Therefore, their effect on carbonation can vary. Proper curing is essential for blended cement concrete. Higher carbonation depth may be found in poorly cured fly ash or slag concrete.

### 6.6 Drying Shrinkage

Drying shrinkage may increase when fine pozzolanic materials increase water demand. Silica fume and RHA may increase shrinkage if water content is not controlled. GGBS and fly ash can reduce heat and cracking but may require proper curing. On top of that, recycled aggregate concrete may exhibit increased shrinkage owing to the appearance of residual adhered mortar and heightened water absorption [13].

Table:1 Comparative summary of results

Waste material	Usual replacement level	Main hardened effect	Main durability effect	Limitation
Fly ash	15–30% cement	Lower early strength, better later strength	Lower permeability and chloride penetration	Slow early reaction
GGBS	30–50% cement	Good long-term strength	Excellent chloride and sulphate resistance	Needs proper curing
Silica fume	5–15% cement	High strength improvement	Very low permeability	High water demand
Rice husk ash	10–20% cement	Improved compressive and tensile strength	Lower absorption and better sulphate resistance	Quality depends on burning and grinding
Sugarcane bagasse ash	5–15% cement	Strength maintained or improved	Better pore structure	Untreated ash may reduce strength
Palm oil fuel ash	10–30% cement	Better later-age strength	Improved permeability resistance	Lower early strength
Waste glass powder	5–20% cement	Strength improvement if finely ground	Better acid and water resistance	ASR risk if coarse
Recycled aggregate	30–100% aggregate	Strength often decreases	Higher absorption unless improved	Old mortar and weak ITZ
Coconut shell	Partial coarse aggregate	Lightweight concrete, lower strength	Higher absorption	Best for non-structural use
Coal bottom ash	Partial sand/cement	Variable strength	Can improve durability if processed	High porosity if untreated

## 7. Discussion

The reviewed literature indicates that waste by products and agricultural residues can yield concrete with comparable or enhanced mechanical strength and durability. The most efficacious supplementary cementitious materials are those endowed with pozzolanic or

latent hydraulic reactivity examples include SF, (RHA), (GGBS), fly ash, sugar-cane bagasse ash (SCBA), and (POFA) which, when incorporated into cementitious matrices, markedly enhance durability and mechanical performance. These materials enhance concrete predominantly by three mechanisms; they exert a filler effect, undergo pozzolanic reactions, and refine the pore structure.

Filler effect occurs when fine particles fill voids between cement grains. This improves particle packing and reduces capillary pores. Pozzolanic reaction occurs when silica-rich waste reacts with C-S-H gel. Refining the pore structure of a material slows the movement of water, chloride ions, sulphates, and acids through it, which increases its durability and resistance to chemical damage.

However, waste material performance is not uniform. Identical materials may yield different findings based on provenance, firing temperature, particle fineness, chemical composition, and curing. Agricultural ash composition is heterogeneous, since uncontrolled combustion can generate crystalline silica or elevated carbon levels. These reduce pozzolanic activity and increase water demand.

Recycled aggregate and coconut shell behave differently from pozzolanic ashes. They replace natural aggregate rather than cement. Their main limitation is higher absorption and lower stiffness. Therefore, their use often reduces strength. On top of that, when blended with supplementary cementitious materials, they retain utility in non structural and lightweight concrete, in pavements, and in sustainable construction.

## 8. Conclusion

Waste by products and agricultural wastes can greatly improve the sustainability of mixture in real world settings. From the reviewed studies, the conclusions are:

At optimal replacement levels, pozzolanic wastes (RHA, SF, FA, SBA, PoFA, and waste glass powder) improve hardened properties and durability.

GGBS is highly effective for improving long-term strength, chloride resistance, sulphate resistance, and permeability resistance.

Rice husk ash generally performs well at 10–20% cement replacement when properly burned and ground.

Sugarcane bagasse ash performs best at low to moderate replacement levels, usually 5–15%.

A related point is that POFA enhances later age performance, although at high replacement levels it may compromise early age strength.

Ground waste glass powder can enhance strength and durability, but coarse glass may cause alkali silica reaction in real world settings. The addition of pozzolanic materials enhances the working of recycled aggregate concrete, although diminished strength and elevated absorption may nonetheless be manifested.

Agricultural lightweight aggregates, with coconut shell as a salient example, confer desirable reductions in concrete density and improved thermal performance for lightweight concrete applications, but they customarily attenuate the material's mechanical strength. Excessive replacement levels generally reduce strength because of dilution, poor packing, high water demand, or weak interfacial transition zones.

Proper curing, material processing, fineness, and mixture design is important for successful waste-based concrete.

## References

1. Arel, H. Ş., & Aydin, E. (2018). Effects of CaO/SiO<sub>2</sub> molar ratio and curing conditions on the microstructure and mechanical properties of alkali-activated slag/fly ash concretes. *Construction and Building Materials*, 181, 173–183.
2. Chindapasirt, P., Rukzon, S., & Sirivivatnanon, V. (2010). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. *Construction and Building Materials*, 22, 932–938.
3. Fernando, A., Selvaranjan, K., Srikanth, G., & Gamage, J. C. P. H. (2022). Development of high strength recycled aggregate concrete: Composite effects of fly ash, silica fume and rice husk ash as pozzolans. *Materials and Structures*, 55, 185.
4. Gesoglu, M., Güneysi, E., & Özbay, E. (2012). Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. *Construction and Building Materials*, 23, 1847–1854.
5. Rashad, A. M. (2015). A brief on high-volume Class F fly ash as cement replacement: A guide for civil engineer. *International Journal of Sustainable Built Environment*, 4(2), 278–306.
6. Oner, A., & Akyuz, S. (2011). An experimental study on optimum usage of GGBS for the compressive strength of concrete. *Cement and Concrete Composites*, 29, 505–514.
7. Siddique, R., & Bennacer, R. (2012). Use of iron and steel industry by-product GGBS in cement paste and mortar. *Resources, Conservation and Recycling*, 69, 29–34.
8. Teng, S., Lim, T. Y. D., & Sabet Divsholi, B. (2013). Durability and mechanical properties of high strength concrete incorporating ultra fine ground granulated blast-furnace slag. *Construction and Building Materials*, 40, 875–881.
9. Chusilp, N., Jaturapitakkul, C., & Kiattikomol, K. (2010). Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars. *Construction and Building Materials*, 23, 3523–3531.
10. Jaturapitakkul, C., Tangpagasit, J., Songmue, S., & Kiattikomol, K. (2011). Filler effect and pozzolanic reaction of ground palm oil fuel ash. *Construction and Building Materials*, 25, 4287–4293.
11. Siddique, R. (2011). Utilization of silica fume in concrete: Review of hardened properties. *Resources, Conservation and Recycling*, 55, 923–932.
12. Zhang, Z., Zhang, B., & Yan, P. (2016). Hydration and microstructures of concrete containing raw or densified silica fume at different curing temperatures. *Construction and Building Materials*, 121, 483–490.

13. Gesoglu, M., Güneyisi, E., & Özbay, E. (2012). Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. *Construction and Building Materials*, 23, 1847–1854.
14. Nili, M., & Afroughsabet, V. (2010). The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete. *Construction and Building Materials*, 24(6), 927–933.
15. Farrant, W. E., Babafemi, A. J., Kolawole, J. T., & Panda, B. (2022). Influence of sugarcane bagasse ash and silica fume on the mechanical and durability properties of concrete. *Materials*, 15(9), 2018 .
16. Ismail, Z. Z., & Al-Hashmi, E. A. (2011). Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Management*, 29, 655–659.
17. Rashad, A. M. (2014). Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement. *Construction and Building Materials*, 72, 340–357.
18. Ataria, R. B., Wang, Y., & Alam, M. S. (2022). Mechanical properties and durability performance of concrete made with 100% recycled aggregates and crumb rubber. *Materials*, 15(5), 1776.
19. Dabiri, H., Kheyroddin, A., & Kaviani, A. (2022). Compressive strength of concrete with recycled aggregate: A machine learning-based evaluation. *Results in Engineering*, 13, 100353.
20. Kou, S. C., & Poon, C. S. (2012). Enhancing the durability properties of concrete prepared with coarse recycled aggregate. *Construction and Building Materials*, 35, 69–76.
21. Limbachiya, M., Meddah, M. S., & Ouchagour, Y. (2012). Use of recycled concrete aggregate in fly-ash concrete. *Construction and Building Materials*, 27(1), 439–449.
22. Mohseni, E., Saadati, R., Kordbacheh, N., Parpinchi, Z. S., & Tang, W. (2017). Engineering and microstructural assessment of fibre-reinforced self-compacting concrete containing recycled coarse aggregate. *Journal of Cleaner Production*, 168, 605–613.
23. Poon, C. S., Kou, S. C., & Lam, L. (2012). Use of recycled aggregates in molded concrete bricks and blocks. *Construction and Building Materials*, 16, 281–289.
24. Ramasamy, V. (2012). Compressive strength and durability properties of rice husk ash concrete. *KSCE Journal of Civil Engineering*, 16(1), 93–102.
25. Chindaprasirt, P., Rukzon, S., & Sirivivatnanon, V. (2010). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. *Construction and Building Materials*, 22, 932–938.
26. Fapohunda, C., Akinbile, B., & Shittu, A. (2017). Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement: A review. *International Journal of Sustainable Built Environment*, 6(2), 675–692.
27. Habeeb, G. A., & Mahmud, H. B. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Materials Research*, 13(2), 185–190.
28. Kannan, V., & Ganesan, K. (2014). Chloride and chemical resistance of self-compacting concrete containing rice husk ash and metakaolin. *Construction and Building Materials*, 51, 225–234.
29. Karim, M. R., Zain, M. F. M., Jamil, M., & Lai, F. C. (2011). Strength of mortar and concrete as influenced by rice husk ash: A review. *World Applied Sciences Journal*, 19(10), 1501–1513.
30. Noorvand, H., Ali, A. A. A., Demirboga, R., Farzadnia, N., & Noorvand, H. (2013). Incorporation of nano TiO<sub>2</sub> in black rice husk ash mortars. *Construction and Building Materials*, 47, 1350–1361.
31. Bheel, N., Memon, A. H., Khaskheli, G. B., Talpur, M. A., & Jawaid, M. (2021). Effect of sugarcane bagasse ash and marble waste on fresh and hardened properties of concrete. *Materials Today: Proceedings*, 46, 1049–1055.
32. Farrant, W. E., Babafemi, A. J., Kolawole, J. T., & Panda, B. (2022). Influence of sugarcane bagasse ash and silica fume on the mechanical and durability properties of concrete. *Materials*, 15(9), 2018.
33. Alsubari, B., Shafiq, P., Jumaat, M. Z., & Alengaram, U. J. (2022). Self-compacting concrete containing high-volume palm oil fuel ash. *Sustainable Buildings*, 7, 1–12.
34. Chandara, C., Sakai, E., Azizli, K. A. M., Ahmad, Z. A., & Hashim, S. F. S. (2010). The effect of unburned carbon in palm oil fuel ash on fluidity of cement pastes containing superplasticizer. *Construction and Building Materials*, 24(9), 1590–1593.
35. Chindaprasirt, P., Rukzon, S., & Sirivivatnanon, V. (2010). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. *Construction and Building Materials*, 22, 932–938.
36. Jaturapitakkul, C., Tangpagasit, J., Songmue, S., & Kiattikomol, K. (2011). Filler effect and pozzolanic reaction of ground palm oil fuel ash. *Construction and Building Materials*, 25, 4287–4293.