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# A REVIEW OF ECO-FRIENDLY MATERIALS IN CONCRETE

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**Abstract**

*The paper investigated the use of environmentally friendly cement alternatives as innovative, cost-effective and sustainable solutions that contribute to the transition to a circular economy by reducing the consumption of natural resources. In addition, the use of waste or recycled materials in concrete to replace aggregates is increasingly being adopted as a sustainable construction practice, due to its significant environmental and economic benefits.*

*Study has demonstrated that integrating waste materials such as fly ash, bottom ash, coal ash, tires, steel slag, construction and demolition debris, glass, and ceramics into concrete can maintain acceptable performance while reducing energy demand, greenhouse gas emissions, production costs, and other related impacts.*

**Keywords**: *Eco-friendly building materials, recycled aggregate, sustainable concrete.*

## 1. Introduction

The world is becoming increasingly polluted, and the living environment of humankind on this planet is under growing threat. Within just a few decades, environmental pollution, especially air pollution and global climate change due to greenhouse gas emissions, has become more evident, and human health is at alarming risk [1].

The construction industry is one of the largest consumers of materials. It also exploits the greatest share of natural resources such as aggregates, minerals, soil, water, energy, and vegetation to build civil, industrial, and transportation works. At the same time, this sector discharges a substantial amount of waste into the environment, including solid waste, greenhouse gases $CO_2$, and noise pollution, all of which contribute significantly to environmental degradation. Top greenhouse gas $CO_2$ emission by country in 2021 was shown in Figure 1 [1].

Therefore, in order to protect the current living environment and preserve it for future generations, researching and applying new environmentally friendly materials to reduce the exploitation of natural resources has become an urgent necessity. This issue

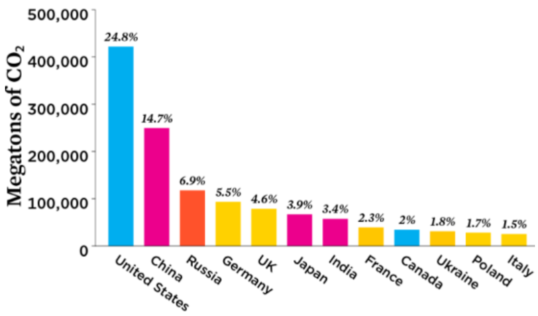


***Figure 1. Top $CO_2$ emission (from fossil fuels and cement) countries until 2021 [1]***

is particularly critical in the field of construction.

Construction works play a vital role in the process of national development. The economic efficiency of a construction project largely depends on its service life. However, the durability of structures is heavily influenced by the rational selection of sustainable materials that can withstand both operational demands and environmental impacts [2].

In recent years, some construction projects in Vietnam have not achieved the expected service life. Numerous failures have occurred due to the inappropriate use of materials, leading to high costs for construction, maintenance, repair, and rehabilitation. Consequently, the efficiency of the investment is diminished, accompanied by substantial negative impacts on the environment.

Cement production constitutes a significant source of environmental pollution, primarily due to $CO_2$ emissions generated during manufacturing and delivery processes, as illustrated in Figure 3 [3]. Moreover, cement production is an energy-intensive process that requires a large amount of resources. World wide cement production in 2018 and forecast to 2030 is shown in Figure 2. To address this challenge, the adoption of sustainable alternatives in the construction industry offers a viable way to reduce $CO_2$ emissions, cut costs, and promote the recycling of waste materials [4]. Reducing greenhouse gas emissions requires both recycling of waste products and conservation of natural resources. Increasing the proportion of recycled aggregates and cement-based

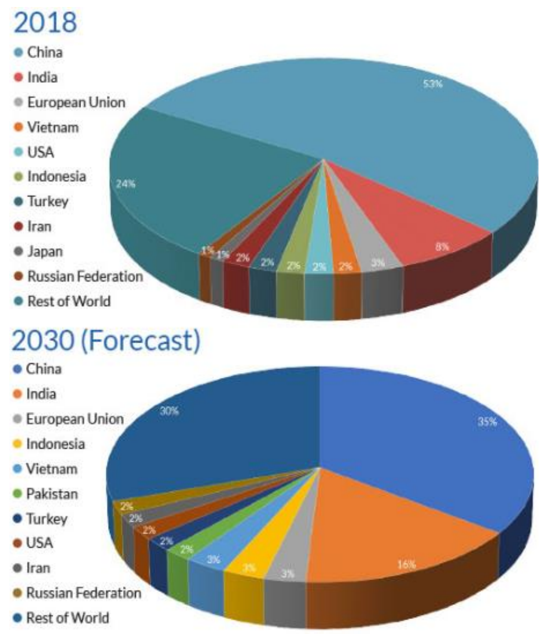


*Figure 2. World wide Cement Production 2018 & Forecast 2030 [2]*

components in concrete improves the material's environmental friendliness [5].

In addition, the partial replacement of cement with sustainable alternatives can improve the durability of concrete, thereby reducing the need for regular maintenance of structures [6].

Based on the above analysis, this paper examines the importance of environmental impact assessment in the process of material selection, design, and application in construction to minimize pollution. in addition, improving material durability and using appropriate alternatives to ensure long life are necessary measures.

## 2. Materials as cement replacement

### *2.1. Industrial by-product materials*

#### *2.1.1. Blast furnace slag*

Blast furnace slag is a by-product of the steel industry, with great potential for use as a component of concrete. In theory, blast furnace slag can completely replace Portland cement; However, in practical applications, the replacement rate is usually around 70%. Depending on the intended use, slag can be used as a binder or aggregate. When used as a binder, slag can replace about 70-80% of the cement mass.

The addition of blast furnace slag in concrete mixtures increases the workability of the mixture, improves long-term compressive and flexural strengths, reduces water permeability, and improves durability and resistance of concrete. Although the cost of slag is comparable to Portland cement, improper disposal in landfills can cause emissions of toxic chemicals. However, when safely integrated into concrete, blast furnace slag provides significant benefits in both environment and material performance [6].

#### *2.1.2. Silica fume*

Silica fume is an ultra-fine pozzolanic material created as a byproduct in the production of silicon metal or ferrosilicon alloys. Thanks to its extremely small particle size and very high pozzolan activity, silica fume has become a widely used supplementary cementitious material (SCM) in concrete with high performance and great durability.

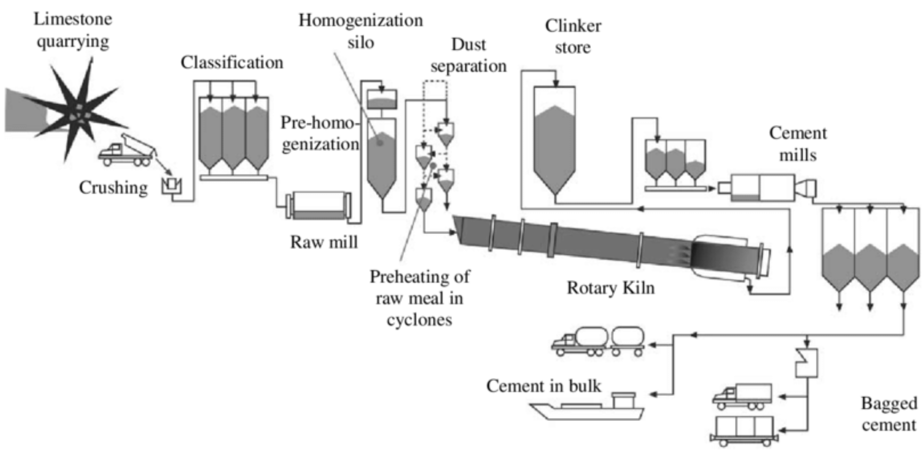


*Figure 3. Cement manufacturing process [3]*

Silica fume can replace about 7-12% of the cement in concrete, making it the third most commonly used cementitious supplement. The addition of silica black significantly improves the properties of concrete by reducing water permeability, increasing long-term durability and enhancing compressive strength. Although its very fine particle size causes some difficulties during processing and application, the cost-effectiveness of silica fume makes it widely used in the construction industry [7].

### *2.1.3. Fly ash*

Significant amounts of fly ash are produced as a residue from coal-fired power plants, with much of it traditionally disposed of in landfills. When employed in concrete as a partial cement replacement, fly ash reduces water demand, enhances workability, and improves paste behavior. Its application can lower cement use by up to 20%, while also reducing the heat of hydration. Key benefits of fly ash include lower cost compared with Portland cement, reduced bleeding, greater strength, and less shrinkage than conventional concrete. Nonetheless, the performance of fly ash-concrete differs according to the specific type and source of the material [8].

### *2.1.4. Bottom ash*

Bottom ash is a non-combustible residue from power generation and waste incineration processes. Produced in significant amounts by the electricity sector, it presents both economic and environmental challenges . Composed mainly of silica, alumina, and iron, with smaller fractions of calcium, magnesium, and sulfates, its composition varies by source and affects the performance of concrete. The use of bottom ash in concrete often reduces strength due to higher porosity and water demand . Denser than fly ash, it can also remain toxic after recycling. Nevertheless, bottom ash has found practical use in construction applications, including railroad fill, abrasive blasting, asphalt roofing, and as aggregate for concrete and masonry units [9].

## ***2.2. Agricultural by-product materials***

### *2.2.1. Rice husk ash*

It is one of the most abundant agricultural residues in rice-producing countries such as Vietnam, Thailand, China Russia, America. Characterized by its pozzolanic reactivity, rice husk contains approximately 30-50% organic carbon. In traditional processing, husks are removed to produce brown rice, which upon further milling yields white rice. Globally, rice production is estimated at about 700 million tons annually, with rice husk accounting for roughly 20% of the total grain weight. When utilized as rice husk ash (RHA), partial replacement of cement-typically around 15%-can enhance concrete compressive strength by nearly 20%. Mechanical and durability properties were observed at substitution rates up to 25%, while higher rates may cause a slight strength reduction of about 4.2%. Because rice husk ash has a relatively high permeability, strict control of the water-to-cement ratio is essential when using rice husk ash in concrete mixtures [10].

### *2.2.2. Wood ash, bagasse ash*

Wood ash and bagasse ash are maijorly produced as residual products after the combustion of wood and sugarcane waste - materials that largely originate from construction activities and are commonly used as fuel in a variety of industrial processes. Many studies have demonstrated that wood ash and bagasse ash can partially replace cement in concrete mixtures at a ratio of about 15-20% without causing a significant decrease in compressive strength compared to conventional concrete [11], [12].

The addition of these ash not only improves sustainability in construction through reducing cement consumption but also contributes to reducing material costs. In addition, concrete containing wood ash also shows improved thermal insulation properties. However, partial replacement of cement with wood ash or bagasse ash has also been reported to reduce the workability of fresh concrete mixtures and increase water absorption [11].

## ***2.3. Recycled building materials***

### *2.3.1. Recycled concrete waste*

Concrete obtaining from demolished structures can be crushed to create recycled aggregate for reuse in new construction projects, thereby reducing landfill waste and the need to exploit natural resources. A considerable proportion of construction and demolition waste consists of bricks and concrete, materials with great potential recycling. Both recycled brick and concrete powders can serve effectively as partial cement substitutes or binders in cement-based materials. Studies have shown that incorporating 5-7% brick powder achieves performance levels comparable to conventional concrete. However, the main drawback of concrete powder is its negative influence on compressive strength. For instance, a 10% replacement of cement with concrete powder leads to an approximate 25% reduction in compressive strength,

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with further increases in substitution causing similar declines [13], [14]. The processing stages for producing recycled construction materials powder are illustrated in Figure 4.

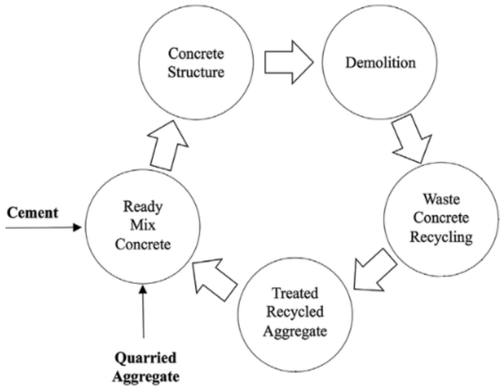


*Figure 4. Recyled concrete waste process [14]*

### *2.3.2. Ceramic waste powder*

Ceramic waste is generated in large quantities in the construction sector as a result of urbanization such as tiles, sanitary ware, and tableware. Ceramic waste, typically generated as a fine powder, poses environmental risks due to its potential toxicity to soil, water, and air. Nevertheless, it has demonstrated significant potential as a partial substitute for cement in concrete production. Its utilization not only reduces the consumption of natural raw materials but also contributes to environmental sustainability. Incorporating ceramic waste powder into concrete enhances workability and durability properties. However, its use may result in slower development of compressive strength and extended setting times [15] .

### *2.3.3. Recycled glass powder*

A substantial amount of waste glass is generated annually from household activities, much of which is often disposed of in landfills without treatment. Due to its physical properties, which are comparable to those of sand, waste glass can be utilized as a binder or aggregate in concrete. After being crushed in a breaker and subsequently milled, the material is sieved to obtain granulated particles. Recycled glass powder is commonly applied in surface treatment through blasting, as reinforcement in synthetic resins, and in the construction of footpaths [16]. The processing stages for glass powder are illustrated in Figure 5.

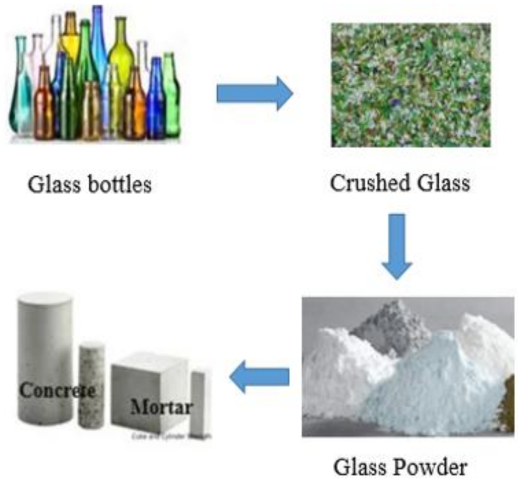


*Figure 5. Recycling waste glass powder in concrete [16]*

## 3. Materials as aggregate replacement

### *3.1. Recycled Waste Tire*

Recycled waste tire was illustrated in Figure 7. Tires are non-biodegradable materials with a relatively short service life of around four years. Discarded tires represent one of the most problematic waste streams, raising both environmental and public health concerns. They provide favorable conditions for pest breeding and pose serious fire risks . To obtain ground rubber particles in the size range of 0.075-0.475 mm, a two-stage process involving magnetic separation and screening is employed. However, replacing more than 20% of cement with tire rubber in concrete can negatively impact compressive

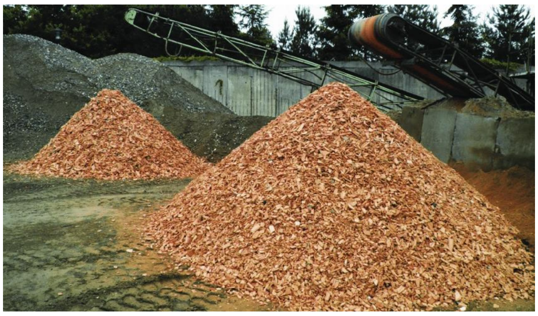

*Figure 6. Waste ceramic aggregate*
*(photo by J. Katzer, Source: ResearchGate.net)*

*Figure 7. Recycled waste rubber tyres [16]*

strength. For this reason, rubberized concrete is generally applied in areas with lower strength requirements, such as low-rise buildings, pavements, parks, slabs, and farms, where slip resistance is beneficial. Additionally, tire-derived rubber serves as an effective sound insulator, making it valuable for construction applications [17].

### *3.2. Recycled waste plastic*

Over the past five decades, the production of plastic materials has grown steadily worldwide. Poor recycling and waste management practices have led to significant ecological impacts. A potential way to reduce this problem is to incorporate recycled plastics into sustainable concrete. It is reported that recycled plastic concrete achieved compressive strength comparable to asphalt concrete and, in some cases, to Portland cement concrete, while also exhibiting lower thermal sensitivity than asphalt concrete [18]. Lightweight aggregates derived from waste polyethylene terephthalate bottles and modified with ground blast furnace slag showed that the density and specific gravity of these aggregates were reduced by almost 50% compared to natural aggregates [19].

### *3.3. Crushed glass*

Glass waste is generated in large quantities from household and industrial sources. Glass has many outstanding properties such as transparency, abrasion resistance, high durability and ease of manufacture. With the increasing demand for new glass-based applications, global glass consumption continues to increase. Approximately 200 million tons of waste are generated worldwide each year, of which glass accounts for approximately 7%. When used as an aggregate in concrete, glass can improve the workability of the mix, reduce bleeding and segregation. However, concrete containing glass typically has lower mechanical strength and higher drying shrinkage, while being more resistant to chemicals, fire and carbonation [20].

### *3.4. Ceramic waste*

Ceramic waste used as aggregate is shown in Figure 6. Experimental results show that the use of ceramic grinding mixture instead of coarse aggregate has a very good role of curing concrete from the inside, and can be combined with fly ash to contribute to improving the quality of concrete.

Crushed ceramic in concrete acts as an internal curing material that increases the strength of normal concrete (without fly ash) by 4-8% and 8-16% for concrete using fly ash to replace 40% of cement by mass.

The use of crushed ceramic mixture in the mix composition reduces the elastic modulus by 8-10% for concrete without fly ash and by 10-14% for concrete containing fly ash to replace 40% of cement by mass. This issue needs to be noted in the design calculation to supplement and arrange reinforcement to suit the load-bearing requirements of the project [5].

## 4. Organic Aggregates

### *4.1. Bamboo*

Bamboo is a fast-growing natural material commonly found in tropical regions that can reach its full mechanical strength in just a few years.

The use of bamboo as reinforcement in masonry walls has been shown to improve shear resistance compared to unreinforced masonry walls, while also exhibiting mechanical behavior similar to that of steel reinforcement.

Researchers have also investigated the replacement of steel with bamboo in structural members such as beams, floors, and columns. The results showed that bamboo can provide sufficient strength, almost equivalent to conventional steel reinforcement.

These findings confirm that bamboo, when used primarily as flexural reinforcement, is not only a viable alternative but in some cases, can outperform steel-reinforced floors [21].

### *4.2. Coconut fiber*

*Figure 8. Coconut Fiber [22]*

Coconut fiber obtaining from the outer shell of coconuts (as shown in Figure 8), has excellent properties for use in concrete. Studies have shown that coconut fiber can withstand deformations 4 to 6 times greater than other natural fibers. In addition, coconut fiber has the highest toughness among all natural fibers. These mechanical properties help reduce

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plastic cracking, making concrete more resistant to bending and impact than conventional concrete. However, the addition of coconut fiber to concrete can lead to a decrease in compressive strength and workability of the mixture [22].

### *4.3. Nanocellulose fiber*

The addition of cellulose nanofibers as reinforcement in concrete can improve both the mechanical properties and service life of the material. Studies have shown that concrete mixtures using nanofibers extracted from waste algae and commercial cellulose nanofibers added to the cement matrix. For samples containing 1.0g of algae cellulose nanofibers, the flexural strength increased to 5.96 MPa, which is an increase of 3.74MPa compared to the control concrete sample without nanofibers. In contrast, samples containing commercial cellulose nanofibers showed a slight decrease in flexural strength compared to the control sample. These results suggest that algae cellulose nanofibers, with their abundant and durable properties, can serve as an effective reinforcing material in concrete [23].

## 5. A case study on the use of environmentally friendly materials in concrete

This section summarizes the findings from a study by Pham et al. [5] in order to analyze the benefits of using environmentally friendly materials in concrete.The study investigates the effect of crushed ceramic waste, derived from discarded bricks and tiles, on the compressive strength and modulus of elasticity of concrete containing fly ash. Concrete specimens were prepared with a 40% cement replacement by fly ash (by weight) and a 40% volumetric replacement of coarse aggregate with crushed ceramic waste, maintaining a low water-to-cement ratio of 0.3 [5].

The result of compressive strength and elastic modulus of mixtures were showed in the Fig.9. and Fig.10.

The research findings indicate that the use of ceramic as an internal curing material in concrete accelerates the pozzolanic reaction in fly ash-based concrete, thereby contributing to an improvement in its compressive strength. Furthermore, the addition of crushed ceramic as an internal curing material improves the compressive strength of concrete by 4-8% in conventional mixes and 8-16% in fly ash concrete (40% cement replacement). However, it decreases the elastic modulus by 8-10% and 10-14%, respectively. These effects should be considered in structural design to ensure proper reinforcement for load-bearing capacity. The use of fly ash as replacement for cement resulted in the decrease in compressive strength of concrete. The use of fly ash as a partial replacement for cement resulted in a

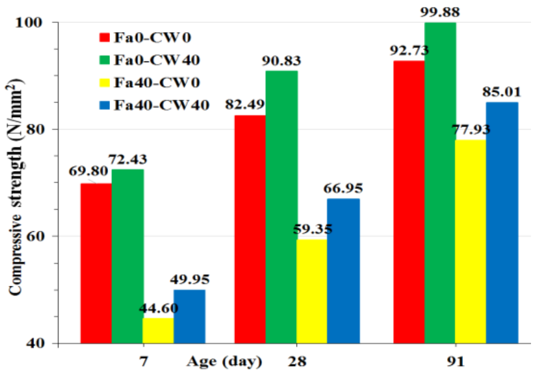


*Figure 9. Compressive strength of concretes with fly ash and ceramic waste [5]*

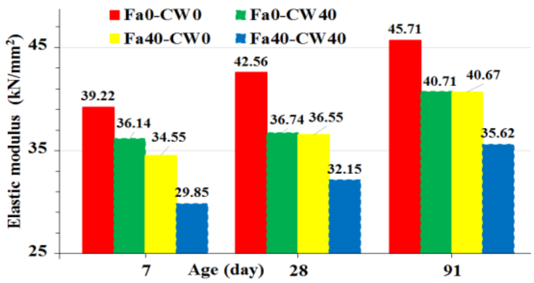


*Figure 10. Elastic modulus of concretes with fly ash and ceramic waste [5]*

*Table 1. Mixture proportion [5]*

| Mixture | Components per cubic meter (kg) | | | | | | Slump (cm) |
|---|---|---|---|---|---|---|---|
| | C | W | Fa | S | G | CW | |
| Fa0-CW0 | 550 | 165 | 0 | 751 | 854 | 0 | 20 |
| Fa0-CW40 | 550 | 165 | 0 | 751 | 512 | 295 | 21 |
| Fa40-CW0 | 330 | 165 | 220 | 751 | 854 | 0 | 21 |
| Fa40-CW40 | 330 | 165 | 220 | 751 | 512 | 295 | 18 |

*C: Cement, W: Water, Fa: Fly ash, S: Sand, G: Coarse aggregate, CW: Ceramic waste* decrease in the compressive strength of concrete. However, the addition of ceramics as aggregate contributed to improving the compressive strength. This enhancement can compensate for the strength loss in concrete mixtures containing both fly ash and ceramics.

In this situation, ceramics acting as an internal curing material in concrete further promote the cement hydration process and the pozzolanic reaction in fly ash-blended concrete, leading to the further generation of calcium silicate hydrate (C-S-H) in the concrete structure, thereby enhancing its strength [5].

## 6. Conclusion

The replacement of cement with supplementary materials may lead to a reduction in the mechanical properties of concrete. However, these disadvantages can be mitigated through the incorporation of advanced materials. For instance, while substituting cement with fly ash often decreases the early-age compressive strength of concrete, the use of ceramic waste as aggregate has been shown to improve the mechanical performance of fly ash concrete.

On the other hand, certain materials such as fly ash, silica fume, and blast furnace slag can enhance the durability of concrete.

The incorporation of recycled materials as aggregates or cementitious agents in concrete, when used in optimal proportions, can enhance both the physical and mechanical properties of sustainable concrete.

Furthermore, these alternative materials not only contribute to reducing $CO_2$ emissions but also play an important role in conserving natural resources and energy.

Sustainable concretes containing organic materials or industrial by-products have shown significant potential in practical applications in the construction industry.

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