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# Towards a sustainable future: Emerging trends in new cement for construction materials

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## Abstract

The research paper offers a detailed analysis of the current trends and developments in new cement production methods to promote sustainable construction materials. The study examines three key areas: Eco-cement, Steel slag concrete, and Municipal slag concrete. Eco-cement involves using waste materials and reducing energy consumption during cement production to conserve natural resources. Steel slag concrete uses steel slag as a binder, including steel slag mixed with fly ash, steel slag with a hydrated matrix, and steelmaking slag with a carbonated matrix. Municipal slag concrete uses ground granulated melt-solidified slag derived from municipal solid waste or sewage sludge as a binder. The research paper aims to focus on contemporary trends and advancements in new cement production for the sustainability of construction materials.

**Keywords:** Eco-cement; Steel slag concrete; Municipal slag concrete; Sustainability; Construction materials

## 1. Introduction

The construction industry is one of the largest contributors to global greenhouse gas emissions, with cement production being a significant contributor to this problem. The production of cement is responsible for approximately 8% of global carbon dioxide emissions, making it one of the most carbon-intensive industries in the world [1]. According to the International Energy Agency (IEA), cement production accounts for approximately 7% of global carbon dioxide ($CO_2$) emissions. The construction industry is facing an increasing demand for sustainable building materials to reduce its environmental impact. Cement, which is the primary binding material in concrete, is one of the most widely used construction materials in the world.

Therefore, the development of sustainable cement formulations is crucial for reducing the environmental impact of the construction industry. However, the production of cement is associated with significant carbon emissions, which contribute to climate change. Therefore, there is a need for new cement formulations that can reduce the carbon footprint of the construction industry. Sustainable construction materials are essential to improve the economic, environmental, and social performance of building materials, while also meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.

One of the most promising developments in sustainable cement is the use of alternative raw materials. These include by-products from other industries such as fly ash from coal-fired power plants and blast furnace slag from steel production. These materials are used as partial substitutes for traditional raw materials in cement production, reducing

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the amount of $CO_2$ emissions associated with cement production. Additionally, using these alternative raw materials can also improve the durability and strength of concrete, leading to longer-lasting and more sustainable buildings [2].

Modern trends and developments in new cement for the sustainability of construction materials include the use of alternative raw materials and the development of low-carbon cement. Alternative raw materials such as blast furnace slag, fly ash, and limestone are being utilized as partial substitutes for traditional raw materials in cement production. These materials can reduce the amount of $CO^2$ emissions associated with cement production and improve the durability of concrete [3]. The shift towards sustainable construction materials and practices is being driven by a growing awareness of the need to reduce the environmental impact of the construction industry. Governments, businesses, and consumers are increasingly recognizing the importance of sustainability in the construction industry and are demanding more sustainable materials and practices. In order to establish a sustainable society, it is imperative to decrease carbon dioxide emissions and efficiently use resources. These objectives are interconnected and can be accomplished by creating innovative cement production methods and finding alternative materials to replace Portland cement in the construction of concrete structures. Research is currently being conducted to investigate potential future manufacturing strategies for new cement that can meet the ongoing need for sustainable construction materials.

The research paper covers the latest trends and advancements in new cement development to promote sustainable construction materials. The study examines three key aspects: Eco-cement, Steel slag concrete, and Municipal slag concrete. Eco-cement is a type of cement that is produced by utilizing waste materials and reducing energy consumption during the manufacturing process. This helps in preserving natural resources. Steel slag concrete is made by using steel slag as a binding material, which can be mixed with fly ash, hydrated matrix, or carbonated matrix. Municipal slag concrete uses granulated slag obtained from municipal solid waste or sewage sludge as a binding material. To keep the discussion concise, the paper will be divided into three sections: Eco-cement, Steel slag concrete, and Municipal slag concrete. The aim is to provide a brief yet informative overview of these topics.

## 2. Advancement in Cement Applications

### 2.1. Eco-friendly cement

Eco-friendly cement is an emerging field of research that focuses on the production of cement with a reduced environmental impact. Cement production is known to be one of the largest sources of carbon dioxide emissions globally. Hence, the need for an eco-cement resources system has become increasingly important. This literature review examines recent studies on eco-cement resources system and highlights the potential strategies for sustainable cement production. One of the key strategies for developing eco-cement is the use of supplementary materials. Supplementary materials are waste products from other industries, such as fly ash, slag, and rice husk ash, which can be used to partially replace Portland cement. The use of supplementary materials in cement production can significantly reduce carbon dioxide emissions and the environmental impact of cement production while improving the mechanical properties of the resulting concrete. Studies have shown that up to 30% replacement of Portland cement with supplementary materials can be achieved without compromising the performance of the concrete [4].

Another promising approach for eco-cement is the use of alternative binders, such as geopolymer and alkali-activated materials. These binders can be produced using waste materials and have a lower carbon footprint compared to Portland cement. The use of geopolymer and alkali-activated materials in cement production can reduce carbon dioxide emissions by up to 80% [5]. Studies have shown that these alternative binders can provide excellent mechanical properties and durability, making them suitable for use in structural applications [6]. Recycling concrete waste is another approach to producing eco-cement. Concrete waste can be crushed and reused as aggregate for new concrete, reducing the need for virgin materials and the associated environmental impacts. The use of recycled concrete aggregate in new concrete production can significantly reduce carbon dioxide emissions and environmental impact, while also improving the durability of the resulting concrete [7,8].

The adoption of eco-cement faces challenges, including the need for standardization, certification, and incentives to encourage its use. However, the potential benefits of eco-cement in terms of reducing carbon dioxide emissions, environmental impact, and improving the durability of concrete are significant. Continued research and development of eco-cement resources systems are essential to overcome these challenges and facilitate the transition to sustainable cement production.

### 2.2. Innovative usage of incinerated ash

Incinerated ash is a byproduct of waste incineration that has the potential to be utilized in various industries. In the construction industry, the utilization of incinerated ash as a substitute for natural resources has been gaining increasing attention in recent years due to its potential economic and environmental benefits. This literature review summarizes the recent advances in the utilization of incinerated ash in the construction industry.

The use of incinerated ash in concrete production is one of the most promising applications. Several studies have shown that the addition of incinerated ash to concrete mixtures can improve the mechanical properties and durability of the resulting concrete [9,10]. The pozzolanic activity of incinerated ash, which refers to its ability to react with calcium hydroxide in the presence of water to form calcium silicate hydrate (C-S-H), is the main mechanism that enhances the properties of concrete. The addition of incinerated ash to concrete can also reduce its carbon footprint by reducing the amount of cement required, which is a significant contributor to greenhouse gas emissions [11].

Apart from concrete, incinerated ash has also been used as a substitute for sand and aggregates in asphalt mixtures. The addition of incinerated ash to asphalt mixtures can improve their stiffness, stability, and resistance to deformation [12]. The use of incinerated ash in asphalt mixtures can also reduce the need for virgin materials and disposal costs for the waste materials. Another potential application of incinerated ash is in the production of bricks. The addition of incinerated ash to brick mixtures can improve their compressive strength and reduce their water absorption [13]. The use of incinerated ash in brick production can also reduce the demand for virgin materials and the amount of waste sent to landfills [14]. In addition to the above applications, incinerated ash can also be used as a soil amendment to improve the fertility and water retention of soils [15]. The addition of incinerated ash to soils can also reduce their acidity and improve their cation exchange capacity, which can benefit plant growth and health.

### 2.3. Contemporary application of wastes and by-products

The construction industry has become a significant contributor to waste generation globally, leading to various environmental concerns. The utilization of waste and by-product resources in the construction industry can reduce waste generation and contribute to sustainable development. This literature review aims to investigate the current state of research on the utilization of waste and by-product resources in the construction industry.

One of the most significant advantages of utilizing waste and by-products in the construction industry is their potential to reduce the environmental impact of the construction sector. Several waste materials have been studied for their potential use in construction, including fly ash, blast furnace slag, and rice husk ash. For example, fly ash, a by-product of coal combustion, has been used in the production of concrete, where it can replace a portion of the cement content. Several studies have shown that the use of fly ash in concrete can improve its strength, durability, and workability [16,17].

One of the most common waste materials used in the construction industry is recycled concrete aggregate (RCA). RCA is produced by crushing and grading waste concrete, and it can be used as a substitute for natural aggregates in the production of new concrete. Several studies have shown that the use of RCA in concrete production can reduce the environmental impact of concrete and provide economic benefits. RCA can also be used as a base or sub-base material in road construction [18].

Another waste material that has gained attention in recent years is blast furnace slag, a by-product of iron and steel production. This material can be used as a substitute for cement in the production of concrete and has been shown to improve its durability and resistance to chemical attacks [19]. Rice husk ash is another waste material that has been studied for its potential use in the construction industry. This by-product of rice milling can be used as a pozzolanic material in the production of concrete and has been shown to improve its compressive strength and durability [19].

The use of incinerated ash in asphalt mixtures can also reduce the need for virgin materials and disposal costs for the waste materials. Another potential application of incinerated ash is in the production of bricks. The addition of incinerated ash to brick mixtures can improve their compressive strength and reduce their water absorption [20].

Apart from waste materials, by-products from other industries can also be utilized in the construction sector. For example, waste tires can be shredded and used as a replacement for aggregate in the production of concrete [21]. This practice not only reduces the amount of waste tires in landfills but also improves the properties of concrete. Similarly, waste glass can be used as a replacement for fine aggregate in concrete production, where it has been shown to improve its strength and durability.

### 2.4. Sustainable mechanism of incinerating ashes

Incineration is one of the most commonly used methods for waste disposal. However, the incinerated ashes produced from this process contain harmful pollutants that pose a threat to the environment and human health. The utilization of incinerated ashes-washing systems in the construction industry has gained significant attention in recent years. The washing system involves washing the incinerated ashes with water to remove harmful pollutants such as heavy metals, dioxins, and furans. The washing system can effectively remove harmful pollutants from incinerated ashes, making them suitable for use as a substitute for natural aggregates in the production of concrete and other construction materials. However, further research is required to investigate the economic feasibility and technical limitations of utilizing incinerated ashes in the construction industry.

Several studies have investigated the effectiveness of the washing system for the removal of pollutants from incinerated ashes. For example, a study by [22] investigated the removal of heavy metals from incinerated ashes using the washing system. The results showed that the washing system was effective in removing heavy metals such as lead, cadmium, and mercury from the incinerated ashes.

The benefits of utilizing incinerated ashes in the construction industry include reduced waste generation, decreased reliance on natural resources, and reduced carbon footprint. Several studies have demonstrated the potential of utilizing incinerated ashes in the production of concrete and other construction materials. For example, a study by [23] investigated the use of washed incinerated ashes as a substitute for natural aggregates in the production of concrete. The results showed that the use of washed incinerated ashes resulted in a significant reduction in the carbon footprint of the concrete.

### 2.5. Sustainable solutions for kiln systems

Applied kiln systems are commonly used in the construction industry for various purposes, including the production of cement, lime, and bricks. The kiln system's operation generates large amounts of heat, which can be utilized to provide eco-services such as waste heat recovery and biomass energy production. This literature review aims to investigate the current state of research on the eco-services of applied kiln systems in the construction industry.

Applied kiln systems can provide various eco-services in the construction industry. One of the significant eco-services is waste heat recovery. The waste heat generated during the operation of the kiln system can be recovered and utilized for various purposes, including the production of electricity, steam, and hot water. Another eco-service provided by applied kiln systems is the production of biomass energy. Biomass energy is generated by utilizing organic waste as a fuel source in the kiln system. The use of biomass energy can significantly reduce greenhouse gas emissions and decrease reliance on fossil fuels.

Several studies have investigated the effectiveness of applied kiln systems in providing eco-services in the construction industry. For example, a study by [23] investigated the potential of utilizing waste heat from cement kilns for electricity generation. The results showed that the waste heat recovery system could generate up to 70 MW of electricity, which could significantly reduce greenhouse gas emissions.

## 3. Applications of Steel Slag

### 3.1. Steel slag concrete

Steel slag is a by-product of steelmaking and has been widely used in the construction industry as an aggregate in concrete. Recent studies have shown that steel slag can also be used as a binder in concrete, producing steel slag concrete. Steel slag concrete in the construction industry has several benefits. Fly ash and steel slag can be used together as partial replacements for cement in concrete production, resulting in concrete with improved properties. Fly ash-steel slag concrete has been shown to have higher compressive strength, lower permeability, and better durability compared to traditional concrete. Another study by [24] investigated the performance of fly ash-steel slag concrete under different curing conditions. The results showed that fly ash-steel slag concrete had better durability and lower shrinkage than traditional concrete under all curing conditions.

Several studies have investigated the effectiveness of steel slag as a binder in concrete. For example, a study by [25] investigated the mechanical properties of steel slag concrete. The results showed that steel slag concrete had higher compressive and flexural strength than traditional concrete. Another study by [26] investigated the durability of steel slag concrete. The results showed that steel slag concrete had lower permeability and better resistance to sulfate attack and carbonation than traditional concrete. Furthermore, several studies have investigated the environmental impact of fly ash-steel slag concrete. For example, a study by [27] investigated the carbon footprint of fly ash-steel slag concrete. The results showed that fly ash-steel slag concrete had a lower carbon footprint than traditional concrete, making it a more sustainable option in the construction industry. However, further research is required to investigate the economic feasibility and technical limitations of using fly ash-steel slag concrete in the construction industry.

### 3.2. Fly ash-steel slag concrete (FS concrete)

Fly ash-steel slag concrete is a sustainable and eco-friendly alternative to conventional concrete, which has gained attention in the construction industry. Its use has the potential to reduce the environmental impact of the construction industry while providing a durable and high-performance building material.

This type of concrete contains fly ash, which is a by-product of coal combustion, and steel slag, a by-product of steel manufacturing. These waste materials are blended with cement, sand, and water to produce a durable and high-performance concrete mixture. The use of fly ash and steel slag in concrete reduces the demand for natural resources and reduces the amount of waste sent to landfills. The addition of fly ash improves the workability, strength, and durability of concrete, while steel slag enhances its mechanical properties and resistance to chemical attacks. Recent studies have reported that fly ash-steel slag concrete has superior compressive strength and tensile strength compared to conventional concrete as well as is less susceptible to cracking and has a lower rate of shrinkage, making it an ideal material for various construction applications. Moreover, fly ash-steel slag concrete has shown excellent performance in aggressive environments, such as exposure to acidic and alkaline solutions.

The incorporation of fly ash and steel slag in concrete production has been shown to improve various properties of the resulting material. A study by [28] found that the use of fly ash and steel slag in concrete significantly improved the material's strength, ductility, and resistance to corrosion. Another study by [29] found that the use of fly ash and steel slag in concrete increased the material's workability and reduced its permeability, making it more resistant to water absorption and damage.

One of the most significant benefits of fly ash-steel slag concrete is its ability to reduce the carbon footprint of concrete production. The use of these materials in concrete reduces the need for cement, which is a major contributor to greenhouse gas emissions. According to a study by [30], the use of fly ash and steel slag in concrete production can reduce carbon emissions significantly, making it a promising solution for the construction industry's sustainability goals.

However, some challenges still exist with the use of fly ash-steel slag concrete. One of the main concerns is the variability of the waste materials, which can affect the consistency and performance of the concrete. Furthermore, the use of fly ash in concrete may also lead to an increase in the permeability of the concrete, which can affect its durability in the long run. Hence, further research is needed to optimize the use of these waste materials in concrete and address the challenges associated with their variability.

### 3.3. Steel slag hydrated matrix

Steel slag, a by-product of the steel industry, is a potential material for use in the construction industry. It is widely available, low-cost, and has high potential as a sustainable alternative to natural aggregates. Steel slag can be used as a partial or total replacement for natural aggregates in concrete mixtures, resulting in the production of steel slag hydrated matrix concrete (SS-HMC). the use of SS-HMC in the construction industry has shown promising results and has the potential to become a viable alternative to traditional concrete mixtures. Further research is needed to optimize the use of steel slag in concrete mixtures and to investigate the long-term performance of SS-HMC in different environmental conditions.

Recent studies have shown that SS-HMC has superior properties compared to traditional concrete mixtures, such as improved strength, durability, and reduced permeability. These properties can be attributed to the unique chemical composition of steel slag, which contains a significant amount of calcium, silicon, and iron oxide. Calcium and silicon react with water during the hydration process, producing calcium silicate hydrates (C-S-H) that contribute to the strength and durability of the concrete. Iron oxide in steel slag also contributes to the formation of C-S-H, which leads to increased strength and reduced permeability [31].

The use of SS-HMC in the construction industry has many benefits, including reducing the amount of waste produced by the steel industry and decreasing the environmental impact of concrete production. In addition, the use of SS-HMC can result in significant cost savings due to its low cost and availability [32].

## 4. Municipal Slag Concrete

### 4.1. Ground granulated slag

Ground granulated blast furnace slag (GGBFS) is a by-product of iron production obtained by quenching molten slag from a blast furnace with water or steam. This industrial by-product has found various applications in the construction industry due to its high reactivity and hydraulic properties, making it an excellent substitute for Portland cement. GGBFS is an eco-friendly alternative to traditional cementitious materials, with significantly lower $CO_2$ emissions and energy consumption during its production. GGBFS is a promising material in the construction industry with various applications. Its use as a partial replacement for Portland cement has shown numerous benefits in terms of strength, durability, and sustainability. The incorporation of GGBFS in construction materials can also contribute to reducing the environmental impact of the construction industry.

In the construction industry, GGBFS has been used as a partial replacement for Portland cement in the production of concrete, mortars, and grouts. It enhances the workability, durability, and strength of concrete, improving its resistance to chloride and sulfate attacks, and reducing the risk of alkali-silica reactions. The addition of GGBFS to concrete also reduces the heat of hydration, thus mitigating the risk of thermal cracking. Additionally, GGBFS can be used as a stabilizer in the production of sub-base and base layers in road construction.

Several studies have reported the benefits of incorporating GGBFS in construction materials. A study by [33] investigated the effect of GGBFS on the mechanical and durability properties of concrete. The results showed that GGBFS significantly improved the compressive strength, split tensile strength, and durability of concrete. Another study by [34] evaluated the performance of GGBFS in stabilizing the subgrade of a highway embankment. The study showed that GGBFS-treated soil had higher strength, reduced plasticity, and better resistance to erosion.

## 5. Conclusion

The cement industry is actively promoting environmentalism by utilizing waste and by-products as raw materials and energy sources in cement production. Various systems have been developed, including the production of eco-cement using incinerated ash as the primary raw material, or using washed Portland cement as raw material and energy source after removing chlorine. Additionally, systems have been developed to convert the garbage into raw material and energy resources through decomposition. Various matrixes have been created using ground granulated blast furnace slag and fly ash, with steelmaking slag used to control expansion. Large-scale blocks can be produced by injecting carbon dioxide gas into a mixture of steelmaking slag. Municipal waste molten slag or low-calcium fly ash with an alkali stimulant has also been developed. The research confirms that new cement manufacturing provides a comprehensive understanding of the characteristics required for creating safe, environmentally friendly, and comfortable urban environments in the sustainable future of concrete technology.

## Compliance with ethical standards

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