An Overview of Eco-Friendly Alternatives as the Replacement of Cement in Concrete

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Abstract. Due to the global urbanization, economic development, and increasing rate of the world’s population, the construction of new buildings and infrastructure is increasing. The manufacture of concrete has become an essential part of our life all over the world. Emitting 5-8% of carbon dioxide (CO₂), the production of concrete becomes the main obstacle to reach global climate action under the Paris 2050 Agreement. Reuse of waste or recycled waste materials in concrete as an environmentally friendly construction material has become highlighted as a feature of achieving sustainability, because of its potential environmental and economic benefits. The focus of this paper is to assess the application of alternative eco-friendly substitutes of cement for an innovative, economically attractive, and environmentally friendly alternative, and the transition towards of circular economy by reducing the number of natural resources consumed. Based on the existing studies, waste material (fly ash, bottom ash, coal ash, tire, steel slag, construction and demolition waste, glass, ceramic) incorporated with concrete accepted performance in the environment and economic perspective by reducing energy consumption, greenhouse gas emissions, costs, and other indicators.

1. Introduction
Increasing awareness of the sustainable construction sector has given rise to using environmentally and economically friendly materials. The construction sector is important all over the world. Being the most frequently used man-made material on earth, it has widespread use in buildings, pavement, pipe, dam, and drain. The major reason behind the expanding demand for concrete are the increased construction of high-rise buildings and its superior high early strength advantage [1,2,3]. Each year more than 10 billion tons of concrete are used worldwide which requires a large amount of raw material [2,3]. Besides, energy consumption during cement production, water consumption, generation of waste during manufacture, demolition, and construction waste recycling difficulty in general concrete is not a sustainable material for future [3,4,5,6]. The main material limestone at the production of cement is the main key factor by releasing 55% of cement-related emissions [1]. Figure 1 shows the increasing rate of cement production globally. Because of the current climate condition and global warming phenomena, it has become indubitable for the construction and other industries from adoption and introduces eco-friendly materials. So, replacing fully or partially cement with recycled material or waste products can reduce the use of raw material also reducing environmental impact. This research aims to find the feasibility of using waste or by-products that can substitute for cement in concrete reducing pressure on raw material use, energy consumption, water requirement, and environmental impact by maximizing resource implementation in concrete through waste recycling system and the transition towards of circular economy by reducing the number of natural resources consumed. Figure 2 shows the waste generation rate in Australia.
To find out which environmental impact, resource, and energy use could be reduced in the construction sector the qualitative techniques used from available official reports, legal documents, and scientific literature and the quantitative data gathered from literature and investigation of local manufacture of cement. This paper summarises the scope of using different eco-friendly materials as a replacement for cement to achieve sustainability.

2. Cement, concrete, and environment

Nowadays, the construction sector is challenged for using many virgin materials and energy as well as environmental effects. Growing concern about the sustainable construction sector had risen awareness of the trend of utilization of waste materials. Green concrete is produced by utilizing waste or residual materials. So, it reduces the burden of landfilling and requires energy for processing [6,7]. Figure 2 shows waste generation by different waste materials in Australia [5]. Cement production contributes to greenhouse gases directly by emitting carbon dioxide when calcium carbonate is heated at 1500°C to 2000°C and indirectly through the use of energy, particularly if the energy is sourced from fossil fuels. As cement production requires a large amount of energy consumption, water requirement, and
environmental impact, so finding a product that can substitute for cement makes good environmental sense. Partial replacement of energy-consuming cement with reusable materials is among the best way to gain sustainable construction material and finding an alternative way to reuse waste materials.

3. Feasible materials as a replacement of cement
At present, one of the main challenges in the concrete industry is to meet the demand for physical and economic awareness. Therefore, a growing awareness of sustainable construction has given the rise to recycling or reusing waste materials in concrete. Mostly from three sources i.e. industry, household/domestic activities, and construction and demolition site waste are generated. The industrial by-product is not a primary product nor separately produced in the industry. It is the remaining material i.e. fly ash, bottom ash, steel slag, foundry sand are common examples of industrial by-products used in concrete [8]. Plastic bags, glass containers, containers are some common examples of domestic waste [9]. Steel, wood products, and plaster, brick and clay tile, asphalt shingles, concretexare some common examples of construction and demolition waste.

3.1. Industrial by-product as a cement replacement

3.1.1. Fly ash. A large volume of fly ash is produced and widely available in coal-burning power plants as a residual material and often ends up in landfills. But when used to make concrete which is a substitute for traditional concrete by utilizing recycled fly ash. Fly ash requires has less water requirement, improved paste properties behavior, and workability. It can reduce 20% of cement demand and 10% of water demand [2, 10]. To reduce the heat of hydration of concrete by replacing the same amount of cement with fly ash is one of the common uses. The main benefits of using fly ash, it can replace a large percentage of cement making it less costly than Portland cement [10], reduced bleeding, increased the strength of concrete, and reduced shrinkage when compared to traditional concrete [11]. Depend on various types of fly ash from different sources performance also get vary.

3.1.2. Silica fume. Silica fume is known as micro silica which is an ultrafine powder. From the condensation of Silicon dioxide in ferrosilicon alloy and silicon manufacture, this is produced as a residual material without any processing. Due to its excellent reactive pozzolan properties, it can replace around 7% - 12% cement in concrete [7]. This is the third most used cementitious substitute material in the concrete industry. The use of micro silica or silica fume has proven durability, less permeability, and increased compressive strength than traditional concrete [12]. Although its microparticle size makes it hard to operate, its cost-effectiveness puts it in high demand in the construction industry [13].

3.1.3. Granular-blast furnace slag. Granular-Blast Furnace Slag is one of the commonly used industrial by-products that can be recycled to make an environmentally friendly alternative to concrete [14]. It is a residual product of the steel industry and it is a glassy granular material. Theoretically, granular blast furnace slag can replace 100% of Portland cement but usually, 70% replacements are in common use. It can be used in concrete either as a binder or as an aggregate. As a binder, it can replace approximately 70–80 wt.% of cement [15]. The benefits of using blast furnace slag are to improve workability, gain higher long-term compressive and flexural strengths, reduced permeability, and improve durability and resilience like fly ash. The cost of using granular blast furnace slag is quite the same as Portland cement but this slag often poses toxic chemicals if it dumps in the landfill. But it can be utilized safely and beneficially in concrete. Here, figure 3 shows some of the commonly used cementitious materials [16].
3.1.4. **Bottom ash.** Bottom Ash is a kind of non-combustible residue of burning in a power plant, boiler, furnace, or municipal solid waste incinerator. The electricity industry is being charged by producing a large amount of bottom ash and it has become an important economic and environmental objective [3]. Its main composition is silica, alumina, and iron with small amounts of calcium, magnesium, sulphate, etc [15]. Its chemical composition is varied by the source. It influences the workability, setting times, strength, porosity, the durability of hardened mass [18]. Here, strength reductions of concrete have mainly happened for higher porosity and higher water demand on the use of bottom ash in concrete. Bottom ash is heavier than fly ash and sometimes it remains toxic after recycling [18]. It has been effectively utilized in construction and railroad fill material, abrasive blasting grit, granules on asphalt roofing shingles, aggregate for concrete and masonry blocks [15].

3.1.5. **Rice husk ash.** Rice husk is the hard-protective coverings of rice grains that are separated from the grains during the rice production process [19]. Rice husk is a common waste material in all rice-producing countries. It is a pozzolanic reactive material that contains about 30–50% of organic carbon [20]. Traditionally, husks are removed from the raw grain to reveal whole brown rice which upon further milling to remove the bran layer will yield white rice. Current rice production in the world is estimated to be 700 million tons [21]. Rice husk obtains around 20% of the weight of rice. By 15% replacement of rice husk ash can increase compressive strength by about 20% in concrete. Strength and durability properties obtain by 20% replacement, beyond that is associated with a slight decrease in strength parameters by about 4.5% [21, 22]. Because of its high permeability, it is often required to maintain the water-cement ratio perfectly [20].

3.1.6. **Recycled waste tire.** The tire is a non-biodegradable material and it has a very short life span of only 4 years. Waste tires are one of the most challenging tricky and problematic waste streams, posing health and environmental concerns [23]. It creates a breeding ground for pests and presenting a significant fire hazard [24]. A two-stage process is used to make the particle into 0.075-0.475mm ground rubber i.e. magnetic separation and screening [25]. But, 20% of replacement may affect the compressive strength of tire rubber in concrete, so it is mostly used in low-strength require places like low rise buildings, parks, slabs, and farms to resist slip [26]. As a sound insulator, it has significant use in the construction sector [27]. Figures 4 and 5 show the different sizes of tire cut and processing.
Figure 4. Different form of rubber aggregate [28,29].

Figure 5. (a) Different size of tire cut [30], (b) powdering process, (c) forms of tire [31].

3.1.7. Waste ceramic powder. During the final polishing process, a large amount of ceramic waste is gathered [32]. Ceramic waste is a toxic powder that is harmful to soil, water, and air. But it has proven useful in concrete as a replacement for cement [9]. It also has a positive environmental impact by reducing the demand for raw materials. The ceramic waste powder has improved the workability and durability characteristics of concrete [33]. The ceramic waste powder can reduce compressive strength development and requiretime. Figure 6 shows the processing process of waste ceramic powder.
3.2. Domestic waste as a replacement of cement

3.2.1. Recycled glass powder. Traditionally, a great amount of waste glass is produced every year in our domestic activities and frequently found untreated in landfills [6]. It can be used as a binder or aggregate in concrete as it has quite the same properties as sand. It becomes granulated by sieving employing sieves after they are crushed in the breaker machine and milled. Recycled glass powder commonly uses for surface treatment by blasting, reinforcement of synthetic resins, and footpath [6,35,36]. Figure 7 shows the processing process of recycled glass powder.

3.2.2. Municipal Solid Waste (MSW) incineration ash. Because of the increasing population, a large volume of municipal waste is often gathered quickly and the lack of landfills also creates problems to dispose of waste. So, nowadays incineration is commonly used to reduce the volume of waste by 85%. But this abundant ash has great performance to increase the strength of concrete. Up to 5% replacement of cement was observed to give the same result as traditional concrete. Ash replacement more than 5%, there is a dramatic loss in strength regardless of curing age [38]. But with the mixture of calcium oxide to the raw mix with 15%, ash replacement can overcome the difficulties. Municipal solid waste incineration ash can replace cement raw mix under a well-conditioned situation [39]. Figure 8 shows the diagram of the MSW incineration process.
3.3. Construction and Demolition by-products as a replacement of cement

3.3.1. Recycled construction and demolition waste powder. A huge percentage of C&D waste is brick and concrete. It can bring a huge potential by using waste brick and concrete [13]. Recycled concrete and brick powders can be successfully used as cement replacements or binders in cement-based products. Replacing 5-7% of brick powder gives the same performance as conventional concrete [40]. The negative effect of concrete powder is mainly influenced by compression strength. Only a 10% cement replacement reduced compression strength by about 25% and a further decrease was almost the same [41]. Figure 9 shows the processing process of recycled construction and demolition in powder form.

3.3.2. Recycled gypsum powder. Construction and demolition waste are the main source of waste gypsum and disposed of unsustainably untreated in landfills. But it has a good role to control the hydration in concrete and controlling the setting time [42]. Approximately 90% of the weight of a piece of drywall is gypsum, if the gypsum can be recovered from the drywall, the majority of the material can be recycled [7,43].
Improved workability, no shrinkage cracks, quick setting time, and high strength is the main added benefit of using gypsum [44]. Although it can replace 20% of cement and provide the same properties as control concrete it is not avoidable for its exceptional hydration properties [42].

3.3.3. Wood ash. Construction waste is the main source of wood waste. It is commonly utilized as burning fuel in various industries [45]. So, wood ash is often found as a residue in wood-burning mills or plants. Due to its excellent properties, wood ash can be used to replace cement partially in concrete production by 15-20% without hampering its strength than traditional concrete [2,46]. Hence, incorporating the usage of wood ash as a replacement for cement in cement is beneficial from the environmental point of view as well as producing low-cost construction materials [2,45]. Thermal insulation properties also get improved in concrete by wood ash. Utilizing of wood ash partial replacement of cement adversely affects the slump of the concrete mix [46]. It is observed an increased rate of water abortion in wood ash content mix [2].

4. Conclusion
In recent years sustainable use of waste or by-products has been accelerated in the construction industry. Whereas the eco-friendly use of alternative waste recycled materials has shown a new path in the concrete industry. The potential way of achieving sustainability can be gained by replacing as much Portland cement as possible with supplementary cementitious materials, especially those that are by-products of industrial processes. Foremost it is the increasing use of cementitious materials that can serve as partial substitutes for Portland cement, those materials that are by-products of industrial processes, such as fly ash and ground granulated blast furnace slag, wood ash, waste glass, waste tire rubber, and construction and demolition waste. But also, the substitution of various recycled materials for aggregate has made significant progress worldwide, thereby reducing the need to quarry virgin materials. However, transport distance of recycling waste, leaching with heavy metals, or recycling process may hinder the potential benefit.

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