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ORIGINAL ARTICLE

Concrete Industry, Environment Issue, and Green Concrete: A Review

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ABSTRACT – Concrete is the second most utilized substance around the world behind the water. The aim of this paper is to review the environmental effect of concrete industry. It has been found that the environmental impact of concrete industry is severe in various environmental categories as global warming, depletion of ozone layer, and acidification of soil and water bodies. Moreover, concrete industry affects ecosystems and alters hydrogeological and hydrological systems. Green concrete has become increasingly popular among researchers and academics in recent years, although it is still in its infancy. This article examines the environmental impact of waste materials such as fly ash, silica fume, and slag as partial or complete replacements for cement, and of waste and recycled material as aggregates. It shows that the negative environmental effect of the concrete industry can be minimized by using these waste materials in the concrete production.

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INTRODUCTION

Due to its excellent mechanical characteristics such as high compressive strength, durability, hardness, workability, and fire resistance, concrete is the most common material used in building construction around the world [1]. Concrete is a building material consisting of a hard, chemically inert component called aggregate (often made of various types of sand and gravel) bound by cement and water. In recent decades, the environmental impact of the concrete industry has attracted much attention as awareness of environmental protection and potential negative consequences have increased at every stage of the concrete industry [2]. Today, the average production of concrete worldwide is about 3.8 tonnes per person per year [3]. Concrete production and consumption are expected to be four times higher by 2050 than in 1990 [4]. The high annual production of concrete means that the consumption of cement and aggregates is also high. In 2019, global cement production reached 4 billion tonnes, a 50% increase from 2005. It is expected to reach over 6 billion tonnes by 2022 [5], with cement production growing by 4% every year, due to the growing population and urbanization [6, 7].

Cement production is a three-stage process involving raw material preparation, clinker production, which consumes a lot of energy; it represents for 12-15 percent of overall energy use globally [8] . The carbon footprint of concrete and cement manufacturing has attracted much attention recently [9, 10]. The production of Cement is accounting for 5-8% of worldwide CO_2 emissions [11, 12]. In addition, several pollutants including, sulfur dioxide (SO_2), nitrogen oxides (NOx), and dust /fine particulates matters (PM) are released into the environment during cement production. These emissions occur at every stage of the cement manufacturing process, from the mining of the limestone to packaging and shipping the finished product [13]. These pollutants have a negative impact on various environmental categories, including climate change, depletion of ozone, and acidification of water and soil.

The concrete production requires the use of a large amount of raw materials; over 27 billion tonnes of raw materials are consumed each year [4]. Concrete's mass demand results in annual aggregate consumption of up to 48.3 billion tonnes [14]. This high consumption is depleting natural resources. In addition, the mining of natural aggregates can promote soil erosion or ecosystem degradation, as the wastewater and sludge released from a concrete plant can affect the aquatic environment. Moreover, the mining processing and transportation of such a large amount of aggregates consume a lot of energy [15], and generate a lot of pollutants such as (CO_2), (NO_X), and (SO_2), which have a severe impact on the environment [16]. In addition, aggregate mining activities can have negative impacts on ecosystems and alter hydrogeological and hydrological systems. These negative impacts of stone and sand extraction can lead to depletion of groundwater, loss of soil fertility, forest deterioration, loss of diversity, and human health problems [17].

Over the past decade, researchers have looked to minimize the adverse effect of the concrete industry on the environment, leading to the development of the idea of green concrete. Green concrete is primarily based on the replacement of cement with industrial and agricultural wastes in concrete and the use of recyclable materials and waste as aggregate [18].

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EMISSION FROM CONCRETE INDUSTRY AND ENVIRONMENT ISSUES

Cement Production Emission

Cement production is an energy-intensive process. Carbonate minerals are dried, crushed, and sintered to produce one kilogram of "clinker" which is then pulverized into cement powder and blended with additional materials, requiring about 3-5 MJ of non-renewable energy [19].The concrete industry is held partially responsible for greenhouse gas (GHG) emissions. The process of cement manufacturing is accounting for more than 70% of GHG emissions in the concrete industry [20]. The primary cause of global warming and climate change is (GHG). Carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are (GHG) associated with climate change. However, CO_2 accounts for 99% of the global warming impact, while other relevant gases are produced in smaller amounts during cement production [21]. During the life cycle of cement production, about 5-8% of worldwide CO_2 emissions are emitted [22]. In 2017, 4.1 Gt of CO_2 was produced during global cement production. This huge amount of CO_2 may lead to the inevitability of man-made climate change [23]. The fossil fuel used in the kiln process accounts for about 40% of CO_2 emissions, while 50% are due to decarburization of the limestone and 10% by transport and handling [24]. In addition to CO_2 emissions, the cement industry also releases Sulfur Dioxide (SO_2). The decomposition/oxidation of sulfides is the primary source of SO_2 emissions in cement production [25]. The cement sector is the third-largest source of SO_2 emissions in China. Therefore, China experiences significant air pollution such as smog and acid rain, with acid rain having harmful effects on agricultural production and plant growth [25].

Moreover, cement production emits Nitrogen Oxide (NO_x).it is produced by thermal oxidation in a rotary kiln [26]. Most (NO_x) is released in the form of (NO) (about 90%) and the rest in the form of (NO_2) [27]. When nitric oxide (NO) comes into contact with oxygen (O_2), it oxidizes to nitrogen dioxide (NO_2), causing NO_x compounds to rise in water and lead to serious environmental problems such as acid rain [28]. In addition, according to Kim and Chae [29], nitric oxide is an important substance that influences the phenomenon of eutrophication. The cement sector in China accounts for 12% of the country's NO_x emissions [30]. In addition, the cement industry releases (PM) such as (PM_{10}) and ($PM_{2.5}$), with (PM) generated during clinker production accounting for the largest share of total emissions (approximately 37%), followed by fugitive emissions from cement grinding (32%). The amount of (PM) released during clinker production ranges from 0.68-1 kg/t [31]. Particulate matter has a negative impact on air quality, leading to many human health problems[32]. In addition, particulate matter is particularly harmful to health because it can interact with hazardous substances such as Cd, As, Cr, Mn, Pb, Ni, Cu, and Zn, which are associated with human-induced activities [33]. It is worth noting that the cement sector in China is a major source of (PM) pollution, representing 30% of total industrial particulate matter emissions [34]. In addition, PM_{10} and $PM_{2.5}$ levels were found to be much higher than permissible around cement plants in a local government district in Nigeria[35]. In 2017, it was also reported that the number of infant deaths due to $PM_{2.5}$ in the Nigerian atmosphere was 49,100, with children under 5 years of age being the most vulnerable[36]. Volatile Organic Compounds (VOCs) are also released into the environment by the cement industry [37]. Incomplete combustion of various fuels contributes significantly to VOCs emissions into the environment [38]. VOCs are caused by ozone formation and can pollute soil and groundwater. Moreover, VOCs have a negative effect on plant growth [39]. In addition, the European cement industry emits 334 - 4670 tonnes of NO_x, up to 11125 tonnes of SO_2, 2.17 - 267 tonnes of VOCs and 460 - 11500 tonnes of CO annually [12]. Table 1 summarizes the impact of the production of one tonne of OPC in different environmental categories.

Table 1. Impact of cement industry in different environmental categories

Impact categories	Unit	Authors		
		[39]	[40]	[30]
Global warming	kg CO_2 eq	964	2160	734.12
Ozone layer depletion	kg CFC-11 eq	$5.4*10^{-5}$	$2.54*10^{-4}$	$1.28*10^{-6}$
Aquatic acidification	kg SO_2 eq	-	-	0.89
Terrestrial acid	kg SO_2 eq	-	7.86	5.58
Aquatic eutrophication	kg PO_4 P-lim	-	-	0.0102
Freshwater eutrophication	kg P eq	0.32	0.138	-
Formation of tropospheric ozone	kg C_2H_4 eq	0.51	-	-
Respiratory inorganics	kg $PM_{2.5}$ eq	-	-	0.23
Respiratory organics	kg C_2H_4 eq	-	-	$3.30 * 10^{-2}$
Particulate matter formation	kg PM_{10} eq	-	3.32	-

Furthermore, noise emissions are released during cement production. Noise pollution is caused by the processing of raw materials, burning of the clinker, storage of the material, and heavy machinery used in this process [41]. Noise pollution in cement plants is divided into gas-dynamic noise, mechanical noise, and electromagnetic noise [42]. Noise pollution has an adverse effect on human health. For example, long-term exposure to high noise can lead to hearing loss [24]. Moreover, in the cement industry, various operations like handling of raw material, crushing of limestone, processing in kilns, manufacturing, and storage of clinker, grinding of finished cement and power supply generate a lot of dust which affects the health of people living near the cement factory [43].

Granite Aggregates Production Emission

Aggregates are among the most commonly used building materials around the world. It is estimated that up to 50 giga tonnes of aggregates are mined annually from quarries, mines, rivers, beaches, and the marine environment. This is forecast to rise to 60 giga tonnes by 2030 [44]. Due to their widespread use, the mining and transportation of large quantities of aggregates have serious environmental impacts. One of the serious environmental impacts of aggregate mining is that almost all-natural vegetation, topsoil, and subsoil must be removed to access the rock beneath the quarries. This leads not only to the extinction of existing species but also to a significant loss of biodiversity as vegetation and aquatic ecosystems are destroyed [45]. In addition, the extraction of natural aggregates produces a large amount of dust that endangers human health and affects the productivity of agriculture [46]. Drilling, blasting, hydraulic hammering, crushing, and screening are the main sources of dust in aggregate production [47]. Furthermore, mining causes noise pollution, which leads to serious health problems such as hearing loss, cardiovascular disease and anxiety [46]. The use of heavy quarry equipment can cause soil erosion, resulting in the accumulation of silt and sediment in downstream streams and rivers [48]. Moreover, the production of aggregates releases pollutants into the air. CO_2 is released throughout the production of aggregates. The key source of CO_2 emissions is the fossil fuels used in the extraction, crushing and screening, handling, and transportation of aggregates. Aggregate mining, handling, and transportation are representing about 13-20% of total CO_2 released in the construction sector [49]. Moreover, each tonne of aggregates emits about 32 kg of CO_2 equivalent of GHG during its life cycle [50]. In the case of granite aggregate, each tonne of aggregate emits about 45.9 kg CO_2 equivalent of GHG [51]. Consequently, the production of natural aggregates has an impact on global warming. Besides CO_2, the production of aggregates also releases SO_2 which has an impact on soil and water acidification. According to Hossain, et al. [50], the production of natural aggregates releases about 1.27 kg of SO_2 per tonne. In addition, fine particulate matter ($PM_{2.5}$) is released during the production of natural aggregates. Natural aggregates emit about 0.0023 kg ($PM_{2.5}$)/tonne, with off-site transportation (43%) and fossil fuel combustion (38%) being the main contributors [52]. Aggregate production releases other pollutants into the air such as C_2H_4, PO_4, and Chloro-fluoro-carbon (CFC) which have various environmental impacts, such as organic respiratory, eutrophication, and ozone layer depletion. Furthermore, the extraction of aggregates releases noise, dust, and contaminated water, which affects ecosystems [53]. It is worth noting that the demand for natural aggregates is increasing. As a result of this demand, the environmental impact of aggregate production is raised up. Figure 1 shows the annual production of crushed stone in the United States in millions of tonnes [54]. It can be observed that a significant increase in production of crushed stone in 2019 compared to 2015 will contribute to an increased environmental impact as well as depletion of natural aggregate resources. The estimated carbon dioxide emissions for annual crushed stone production in the United States are calculated in millions of tonnes as shown in Figure 1. Clearly, higher aggregate production leads to higher CO_2 emissions, which in turn increases the impact of aggregate production on global warming.

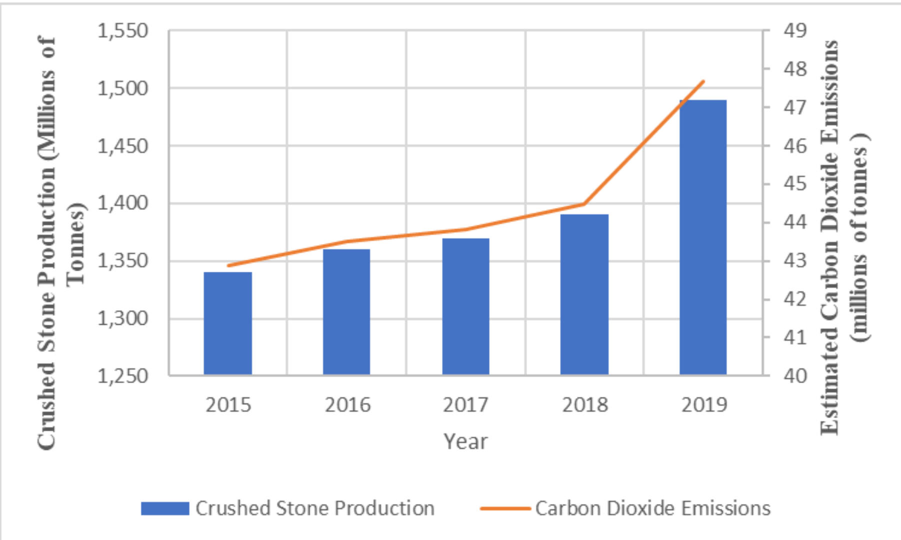

Figure 1. The estimated value of CO_2 emissions (in millions of tonnes) in the United States due to crushed stone on the basis that each tonne of crushed stone emits 32 kg of CO_2 [50, 54]

Fine Aggregate Production Emission

According to Hossain, et al. [50], the production of one tonne of fine aggregate river sand, 341 MJ of non-renewable energy is consumed, resulting in the emission of 23 kg CO_2 equivalent of GHGs, while crushed stone requires 518 MJ of energy and emits 33 kg CO_2 equivalent of GHGs. In addition, the production of one tonne of fine aggregate emits about 0.03 kg $PM_{2.5}$ equivalent and 0.98 kg to 1.29 SO_2 equivalent of terrestrial acid. Furthermore, the production of fine aggregates releases other pollutants that affect the eutrophication of water bodies. The production of one tonne of fine aggregate from river sand releases about 0.0006 kg PO_4 P-lim [50]. Moreover, sand mining leads to the degradation of air quality. Sand mining releases a significant amount of dust that can endanger human health. In addition, sand extraction causes noise pollution and vibrations due to the heavy equipment and blasting used, which affect the quality of life of local residents, and the vibrations can be harmful to surrounding buildings [55]. Furthermore, the quality of surface runoff and groundwater can be affected by sand mining due to dissolved and suspended pollutants. Sediment, also known as suspended solids, is one of the most common contaminants in surface waters. Sediment can choke stream beds, harming fish and benthic organisms [56]. Moreover, sand mining leads to destroys plant and aquatic habitats, leading to loss of biodiversity. e.g., exploitation of sand in rivers leads to deepening of rivers and estuaries and widening of estuaries and coastal bays. This leads to saltwater intrusion [57]. It is worth noting that Sand consumption is increasing at an alarming rate due to ongoing construction projects and other infrastructure improvements, with excessive sand mining causing severe environmental impacts. Figure 2 shows the annual production of sand and gravel in the United States in millions of tonnes. The estimated SO_2 equivalent of terrestrial acid emissions for annual sand stone production in the United States is calculated in millions of tonnes as shown in Figure 2. Clearly, increased aggregate production leads to higher SO_2 emissions, which increases the impact of aggregate production on soil acidification.

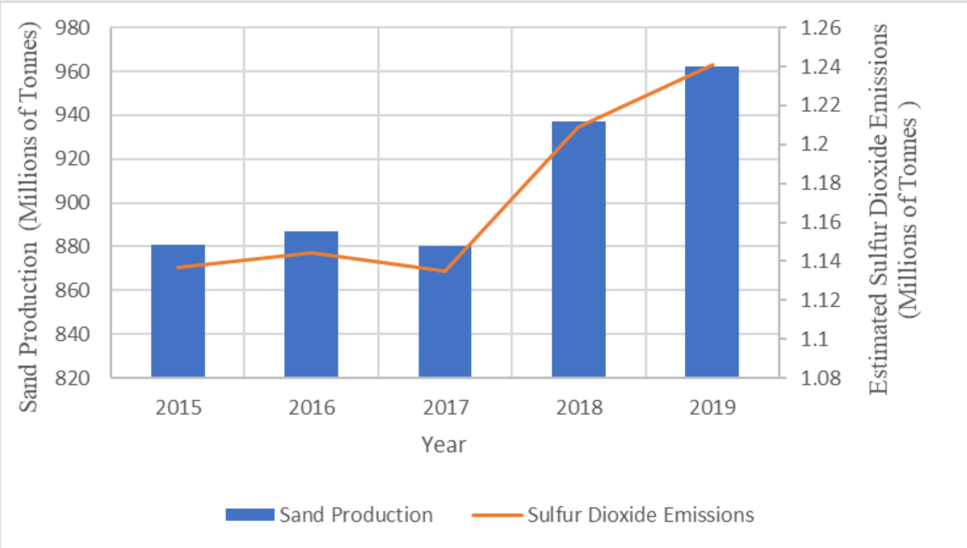

Figure 2. The estimated amount of SO_2 emissions (in millions of tonnes) from sand in the United States, based on the assumption that one tonne of sand emits 1.29 kg of SO_2.[50, 54]

GREEN CONCRETE AS A SOLUTION

Green concrete is a relatively new concept in the history of the concrete industry, as the concept of green concrete was introduced in 1998 [58]. Green concrete is defined as concrete that is produced using at least one waste ingredient, is produced in an environmentally friendly manner, and has good life cycle performance and sustainability [59]. Green concrete has attracted much attention in the concrete industry because it has less impact on the environment, improves concrete properties, and reduces the need for natural resources compared to conventional concrete [60]. Green concrete has several types such as geopolymer concrete, high-volume fly ash concrete [61].

In green concrete, there are several substitutes for ordinary Portland cement, such as supplementary cementitious materials (SCM) and alkali-activated binders (AABs) [62]. All these alternatives depend mainly on agricultural and industrial wastes, including rice husk ash (RHA), fly ash (FA), silica fume (SF), and slag (GBBS) [63, 64]. SCM is used as a partial replacement for OPC up to 50% or more based on the desired characteristics of the concrete [65]. The use of SCM reduces CO_2 emissions throughout the life cycle of concrete production. This is mainly due to the fact that less cement is used in concrete production, which in turn reduces CO_2 emissions from cement production. Furthermore, the use of SCM in concrete not only minimizes the influence on the environment but also improves the concrete properties. For example, FA improves the workability of concrete and extends the setting time without affecting the final compressive strength [66]. RHA improves the concrete durability and increases its resistance to sulfate attack as well as reduces water absorption [67], while slag reduces the heat of hydration of concrete [68]. On the other hand, the alkali-activated binders completely eliminate the use of OPC in concrete, leading to a significant decrease in the environmental influence of the concrete industry. For instance, when AABs are used instead of OPC, CO_2 emissions be reduced by up to 80% [69]. Another method of making green concrete is to use calcium aluminate (CA) and calcium-sulfo-aluminate

(CSA) cements. Using these cement instead of OPC produces green concrete by minimizing CO_2 emissions into the environment. [70].

Natural aggregates are partially or completely replaced by waste and recyclable materials in the production of green concrete. Using these solid wastes as aggregates in concrete eliminates the need for natural aggregates to be mined and processed, helping to conserve natural aggregate sources, manage waste, and decrease total energy and carbon emissions from concrete production [70]. Some of these waste materials are; plastic [71], tire rubber [72], glass [73], coconut shell [74], construction and demolition wastes [75], E-Plastic Waste[76], ceramics[77]. On the other hand, sand is also replaced in whole or in part by waste and recycled materials in the green concrete. The use of waste or recycled material eliminates the negative environmental impact of sand mining and production. Several research have revealed that various waste materials may be employed as a substitute for natural sand in green concrete [78-81]. Therefore, green concrete can take a variety of forms, such as concrete in which OPC is partially or completely replaced, or concrete using waste or recycled materials to replace natural aggregates.

In some studies, Fernando, et al. [82] used life cycle assessment to evaluate the environmental effect of geopolymer concrete made from FA. In this study, the emission of 0.011 kg CO_2- equivalent /kg due to the manufacturing process of FA is considered. Compared to traditional concrete, the results showed 12% less greenhouse gas (GHG) emissions. According to Zhang, et al. [83], (SF) and FA are able to reduce CO_2 emissions in concrete production. The results revealed that using 5% SF as a partial substitution for OPC reduced CO_2 emissions by 3.98%. On the other hand, the use of 15% FA and 5% SF as a partial replacement for cement resulted in an a15.64% reduction in CO_2 emissions compared to OPC concrete. Dandautiya and Singh [84] evaluated the environmental impact of concrete made from (FA) and copper waste (CT) as a partial substitute for OPC. The results showed that a significant reduction in the environmental influence of concrete on climate change and depletion of the ozone. The environmental effect of concrete is reduced when the cement replacement ratio is increased with FA and CT, with lower environmental impacts observed when cement was replaced by 30% of FA and 10% of CT. Moreover, Ersan, et al. [85] investigated the environmental influence of green lightweight concrete. In this study, the aggregate was partially replaced by plastic waste 30%, and the cement was replaced by 20% FA. The results showed that the climate change potential decreased by 13% compared to traditional lightweight concrete. The effects on ozone layer depletion and acidification also decreased compared to traditional lightweight concrete, while the effects on eutrophication increased.

Gursel, et al. [86] studied the environmental effects of various concrete mixes made with a combination of FA and RHA as a partial OPC substitute. The results showed that the use of 40% FA and 15% RHA reduced CO_2 emissions from 544 kg CO_2- equivalent /m^3 to 284 kg CO_2-eq/m^3. In addition, NO_X, PM, and SO_2 were reduced. However, CO emission increases with the increasing use of RHA in concrete. Singh, et al. [87] evaluated the environmental influence of using marble powder as a partial substitute for sand and cement in concrete. The findings showed that using marble powder as a partial substitute for OPC reduces the effect of concrete production on global warming and the depletion of ozone. The CO_2 emission for concrete with 15% marble as a partial substitute for OPC is 350 kg/m^3 compared to 410 kg/m^3 for traditional concrete. Nikbin, et al. [88] studied the environmental impact of substituting bauxite residues for cement. The results of the study show that CO_2 emissions from concrete production decrease significantly. CO_2 emissions decrease from 556.8 kg m-3 to 409.9 kg m^{-3} when bauxite residues replace cement by up to 25%. It can be argued that cement production alone is the main source of CO_2 emissions. Based on the study result, the use of bauxite residues is sustainable even if the transportation distances are much longer than those of the conventionally used cement. In addition, according to Hedayatinia, et al. [89], most of the global warming potential generated in concrete production is due to the cement manufacturing process, which accounts for 92% of the total GWP generated in concrete production.Table 2 summarizes the effects of different admixture in concrete production on the global warming potential due to concrete.

Table 2. The impact of different admixture in concrete production on the global warming potential due to concrete

Source	Concrete Types	Admixture	Replacement Percentage (%)	Global Warming Potential Reduction Percentage (%)
[88]	Lightweight concrete	Bauxite Residue (BR)	25	26.3
[84]	Normal concrete	Fly ash (FA) and copper tailings (CT)	FA 30, and 10 CT	37
[86]	Normal concrete	RHA and Fly ash	FA 40, and RHA 15	51
	Normal concrete	Fly ash (FA)	40, 50, 60, and 70	37, 46, 55, and 64
[91]	Normal concrete	Fly ash (FA)	35	30
	Normal concrete	GGBFS	70	60
[92]	Normal concrete	Fly ash (FA)	25	30
[93]	Normal concrete	Fly ash (FA)	100	75.25
	Normal concrete	Fly Ash (FA), Silica fume (SF)	80 FA, 20 SF	77.71
[94]	Normal concrete	Fly ash (FA)	30, and 60	25, and 52
[95]	Normal concrete	Sewage sludge ash	10	9

CONCLUSION

The environmental effect of the concrete industry has been highlighted in this study. Starting with the raw material extraction to the final product, the environmental impacts of the various concrete production processes are examined. Many environmental problems are affected by the concrete industry, including climate change, depletion of the ozone layer, and acidification of soil and water bodies. In addition, the concrete industry has adverse effects on ecosystems, including loss of biodiversity and alteration of hydrogeological and hydrological systems. Green concrete has recently been presented as a way to minimize the environmental effect of concrete production. Several researchers have investigated the impact of natural wastes, industrial or agricultural by-products, and recycled wastes as aggregates in concrete production as cement alternatives. The use of these wastes in concrete production can reduce the various environmental effect of the concrete industry while enhancing the properties of concrete.

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