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REVIEW ARTICLE

A review of cementitious alternatives within the development of environmental sustainability associated with cement replacement

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Abstract
The environmental conditions of sustainable improvement in manufacturing consist of the application of secondary raw materials in the design and structure of new structures. Presently, the demand to construct new structures is growing rapidly, especially in the developed world. All of the construction and demolition (C&D) waste is deposited in open landfills in easily reachable spaces, which leads to numerous environmental problems. The utilization of this waste in concrete will help in sustainable and greener development. The main goals of using waste, by-products, and recycled materials to develop sustainable concrete are to reduce carbon dioxide emissions, which are a cause of environmental pollution and climate change, and to enhance exploitation of waste, which creates problems of disposal that can be solved by completely or partially replacing concrete components. This paper aims to provide a comprehensive overview of the published literature on the replacement of cement in concrete such as rice husk ash (RHA), olive stone biomass ash (OBA), recycled coal bottom ash (CBA), and recycled palm oil fuel ash (POFA), and its effects on the characteristics of concrete like workability, density, compressive strength, splitting tensile strength, flexural strength, shrinkage, and durability. Also, this paper aims to review the impact of the replacement of cement on sustainability. The author has also included recommendations for future research.

Keywords Sustainable concrete · Cement · Environmental development · Construction and demolition · Rice husk ash · Coal bottom ash · Olive stone ash · Palm oil fuel ash · Replacement

Introduction

In terms of socio-economic advancements, the previous 40 years have seen enormous human activity. According to Intergovernmental Panel on Climate Change, referenced by the World Meteorological Organization, these activities are one of the main reasons for the variation of global climate change (Shaikh 2016). Concrete constructed using cement is undoubtedly one of the most commonly employed structure materials (Amin & Tayeh 2020). Concrete is commonly used in construction because of its remarkable ease of availability of constituent ingredients, durability, ability to be moulded into any shape or size, and low cost (Yildizel et al. 2020b). The techniques employed for manufacturing concrete and binding constituent materials are likewise critical in construction technology as Lakshmi and Nagan (2011) stated. Cement is the most widely utilized binding ingredient in reinforced and unreinforced concrete applications (Amran et al. 2020). Globally, Ordinary Portland Cement (OPC) output is increasing at a rate of 9% per year. This rate of increase in OPC production poses an extreme risk to the environment because of the massive amount of CO_2 discharged into the atmosphere during the cement manufacturing process (Madheswaran et al. 2013). Also, OPC production creates around 1.5 billion tonnes of greenhouse emissions every year (Amran et al. 2020).

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Highlights
- Review of more than 150 research articles on alternatives for the development of environmental sustainability associated with cement replacement.
- The physical and chemical characteristics of alternatives are reviewed.
- The effect of partial cement replacement on fresh, hardened, and durability characteristics of green concrete is reviewed.
- Recommendations for future research.

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The cement manufacturing sector leads 8% of the overall GHG production (CO_2), which is growing at alarming amounts owing to the extraordinary rise of the human population and speedy industrialization (Shahidan et al. 2017; Abdul-Rahman et al. 2020; Das et al. 2020; Tayeh et al. 2020b). Enormous volumes of cement production and concrete construction use large volumes of freshwater (roughly 1 trillion L yearly) for mixtures and curing, causing a significant risk of acute water shortage (Das et al. 2020). Danda et al. (2020) concluded that as the demand for urban and infrastructure development rises the use of concrete rises with it in which OPC is employed as the primary binder (El-Sayed et al. 2022; Hafez et al. 2022). As civil engineers, we are very much concerned about environmental issues related to the manufacture of cement. The volume of CO_2 released into the environment during the manufacture of cement is well known (Almutairi et al. 2021; Tayeh et al. 2021c). This is also accompanied by emission of carbon dioxide due to burning of fossil fuels to generate energy needed for the production of cement (Chun et al. 2008; Sofi & Phanikumar 2015).

Industrial waste generation is one of the most significant global issues that almost all nations are facing today (Jubeh et al. 2019; Alaloul et al. 2021; Haido et al. 2021). Non-biodegradable wastes like clay-based materials and construction and explosion waste take a long time to degrade and are of high priority (Halicka et al. 2013; Pacheco-Torgal & Ding 2013; Medina et al. 2016). One technically viable and economically feasible solution for such non-biodegradable waste could be to use such materials to produce new structural materials (Tobbala et al. 2022). Improving the circular economy across all construction activities could help in the devaluation of raw materials of about 17–24% by 2030 (Medina et al. 2016), with possible overall savings for the European industry of €630 billion yearly. These rates are immediately connected to (a) position and opportunity of natural sources; (b) distance to the origin of natural aggregate; and (c) administrative pressure in the design of legislative and organizational mechanisms that support some form of valorization (Medina et al. 2016).

The reduction of availability of natural resources and the urgent need for their preservation has produced the immediate necessity to discover ways to use alternate materials, mostly agricultural and industrial wastes or by-products (Yildizel et al. 2020a; Amin et al. 2021; de Azevedo et al. 2022). According to International Energy Agency, there is an urgent and essential need to gradually substitute fossil fuels with suitable substitutes. In line with this, the European Union has already committed to targeting the production of 20% of energy using renewable resources by 2020 and 27% by 2030 (Proskurina et al. 2016). Production of energy using wind, solar, hydro, tidal, geothermal, and biomass is categorized as renewable energy (Proskurina et al. 2016; Tsakiridis et al. 2017). Also, researchers explored the using carbon-based nanomaterials (CNTs) in cementitious composites as a reinforcement (El-Sayed et al. 2022). The results indicated that CNTs had the potential to be the superior reinforcement for the next generation of high performance and multifunctional cementitious composites due to their extraordinary multifunctional properties (Yazdanbakhsh et al. 2010; Tyson et al. 2011; Ramezani 2019; El-Sayed et al. 2022; Hafez et al. 2022). Ramezani et al. (2022) reported that the outstanding properties of carbon nanotubes (CNTs) have brought great potential for developing high performance, multi- functional, and smart cementitious composites.

The demand to use more sustainable products with low environmental impact has given rise to the need to explore alternate usability of natural materials and reuse of recycled materials and wastes from other industries (Asdrubali et al. 2012; Schiavoni et al. 2016; Martellotta et al. 2018).

Emissions of GHG, mainly from the incineration of burning fossil fuels, are the primary causes of climate change. Per some estimates, the cement industry is responsible for 5–8% of worldwide anthropogenic emissions, and this proportion might rise to 12–23% by 2050 (Andrew 2018; Font et al. 2020). Replacement of clinker up to 15–20% by replacement cementing materials can significantly reduce carbon dioxide emissions while having an acceptable reduction in compressive strength of concrete made with such cement.

This paper explores several options for partial replacing cement to obtain sustainable concrete and presents the chemical composition and physical characteristics of the alternatives (RHA, OBA, CBA, and POFA). Also, this study shows the fresh and hardened characteristics of sustainable concrete. This study displays several important characteristics of concrete, such as workability, density, compressive strength, flexural strength, and split tensile strength. The current study also examines the effect of these alternatives on the durability of concrete and analyzes many characteristics such as water absorption capacity, ultrasonic pulse velocity (UPV), electrical resistivity, and chloride penetration tests. This paper included many recommendations for future studies.

Construction and demolition waste

Construction and demolition waste recycling (C&D-waste) has various steps that include collection, sorting, recycling, storage, transportation, and disposal of such waste. As with recycling of any other type of waste, recycling of C&D-waste also aims at turning C&D-waste into new resources for use (Arafa et al. 2017; Abed et al. 2020). Not all steps mentioned above are necessary for recycling C&D-waste and depend on the end-use of the waste. In case of such a waste intended to be used for land reclamation or backfilling, that is, low-level use, only of on or off-site sorting, or crushing waste into smaller pieces may be the process carried (Tayeh et al. 2020a). This is referred to as curbside and drop-off recycling in municipal solid waste recycling terms (Bohm et al. 2010; Kumbhar et al. 2013).

Currently, the rate of constructing different structures is rising all over the world, especially in the developed world. More than often, the C&D-wastes are deposited in open landfills in near and easily reachable areas leading to numerous environmental issues (Kazemian et al. 2019).

The tremendous negative effects on the environment are caused by the emission of CO_2, the decrease of virgin materials, and the generation of C&D-waste as building activities increase (Rajhans et al. 2019). Reusing and recycling C&D-waste has enormous potential, and it has been a popular study topic for over a century (Matias et al. 2014). After basic classification and preparation, C&D-waste has huge potential in the building sector as a sustainable resource (Cabral et al. 2010).

Due to the fast expansion of the construction sector, large amounts of C&D-waste are created internationally (Nagapan et al. 2012). China is the world's largest manufacturer of C&D-waste, with 2.4 billion tonnes generated in 2015 (Duan et al. 2019). Enormous C&D-waste will certainly dominate land resources and become the primary cause of the destruction of natural habitats if adequate waste management is not implemented (Nagapan et al. 2012), as a large amount of C&D-waste is already being dumped in the sea or landfills (Bravo et al. 2015). The majority of these C&D-wastes are concrete, which can be recycled and crushed to be used as aggregates or pulverized to partially replace cement. There is a large production of C&D-waste in the urban areas causing environmental and disposal problems. These waste materials are recycled and can be effectively used in the production of concrete (Rajhans et al. 2018). Recycling C&D-waste that contains 70–75% cement and aggregates (Rajhans et al. 2018) which can help to resolve disposal issues as it will not end up in landfills. Reuse of such waste can decrease the cost of concrete production, and it will help reduce the strain on the environment by requiring fewer virgin aggregates.

Impacts of policies

The production of concrete has noteworthy GHG emissions, with harmful repercussions for the Earth's atmosphere. Climate change, caused by massive concentrations of carbon dioxide and other GHG in the environment, will have a considerable adverse influence on human life. The impacts on the community, such as advanced human sickness and premature mortality, decreased agricultural yields, rising power demands, and reduced freshwater availability, will increase with deteriorating global average weather (Tol 2011). Without any efforts to curb carbon dioxide emissions resulting from the production of concrete, emissions will continue to grow with human demands (Seto et al. 2012). The urban land cover is expected to have risen by 120 million hectares by 2030, approximately double the global urban area of land in 2000.

Di Filippo et al. (2019) reported all over the world, policymakers are now actively working to minimize GHG emissions to limit or even reverse the impact of climate change. Some authorities around the world have established economy-wide policies to limit GHG emissions due to concrete production in a method that significantly influences concrete production and the supply chain. To illustrate, 32 European societies and subnational authorities within the USA, China, and Canada have approved initiatives like carbon-cap (Carl & Fedor 2016). Policymakers aiming to reduce GHG emissions may utilize prescriptive management mechanisms to carry out intended GHG reductions from concrete production. There is a global consensus to curb GHG emissions as 197 nations became signatories of the Paris Agreement in 2015 to address the most pressing issues related to global warming (Nations 2015). Every government is to make and pursue policies that will be implemented by these countries in their own countries to lower carbon emissions originating in their countries, respectively.

While the initial focus is to cut down on the use of fossil fuels for energy production, through alternate renewable sources to lessen CO_2 emissions caused by the usage of fossil fuels. The impact of CO_2 emissions on the cement and concrete industries will be the prime object of upcoming regulation. At its most basic, there are two ways in which authorities and policymakers can minimize GHG emissions: (i) by limiting the activity that causes high emissions by dropping productivity and (ii) by limiting the emissions through alternate actions.

Content requirements may be achieved, but with restrictions. Recycled material content requirements that require a minimal product content shall be used in other applications as a by-product of the primary industry as a method of recycling trash (Palmer & Walls 1997). Comparable content standards targeting GHG emission declines through minimal substances of recycled aggregate, clinker replacements, or substitute types of cement could be used for concrete manufacture. However, since the use of such items impacts the characteristics of concrete, such requirements may not be suitable.

Possible solution methods

Umar et al. (2020) noted that the construction industry worldwide is spending an enormous amount of natural resources and energy. The persistent will for ecological administration has encouraged legislators and professionals to develop and apply uniform systems to administer and minimize the ecological impact of all manufacturing industries, including the construction industry (Patil & Dilip 2012). Due to the rapid urbanization trend that humans have created over the last few decades, the demand to reuse and recycle waste produced by inhabitants of this world and waste created by industries serving these inhabitants is now greater than ever before. Limiting the use of non-renewable resources on our planet and proper waste management to reuse the waste of one segment of society as a raw material for another, even beyond the first service life of the material, are proving to be effective strategies for the preservation of the environment (Duan et al. 2010).

The modern problem for construction professionals is to decide whether to use recycled materials or virgin resources to construct new structures and, in the end, either to properly recycle waste generated on their site or dump it in a landfill. To minimize the waste generated on construction sites, it is important that all the stakeholders are on the same page and proper waste management is done with strategy during all phases of a construction project, including planning, design, and construction, as a significant volume of structural waste is generated due to inappropriate practices (Umar et al. 2017).

With appropriate waste management, one may reduce the demand for new resources, lower the cost of using energy in construction and transportation, and repurpose waste items that would otherwise be disposed of in landfills (Fakhretaha et al. 2013; Yuan 2013; Askarian et al. 2018; Shafiq et al. 2018; Zahid et al. 2018). Aside from environmental concerns, the scarcity of land for trash disposal and the high costs connected with a garbage disposal are major factors driving experts in the worldwide construction sector to recycle C&D-waste (Behera et al. 2014).

Proper reuse of waste material can conserve power and cut down on CO_2 emissions. Recycling of several waste materials requires less energy as compared to preparing virgin materials from natural resources and can likewise cut down on required transportation and its related environmental impact. There are many possible methods presented in previous studies, some of which were mentioned above. It is possible to use the disposal, recycling, or reusing of wastes or construction wastes. Moreover, Fig. 1 shows the hierarchy of sustainability.

Fig. 1 Sustainability hierarchy (Charleston 2018)

Sources

Rice husk ash (RHA)

RHA has significant potential for usage as a supplemental cementitious ingredient in composite cement manufacture. Several studies suggest that using RHA as a partial substitute for cement improves the mechanical and durability characteristics (Habeeb & Mahmud 2010; Chao-Lung et al. 2011; Kim et al. 2014; Kishore & Gayathri 2017). RHA has also been studied for use in the production of geopolymer concrete (Kim et al. 2014; Kishore & Gayathri 2017). Despite this, the use of RHA in the construction sector is still limited owing to a lack of evidence of the favorable benefits of RHA mixtures on concrete physical characteristics (Habeeb & Mahmud 2010). Since large volumes of RHA are formed during the per-boiling process of rice in rice mills, attention must be focused on studying the usage of RHA in composite cement manufacture in the future. RHA's pozzolanic characteristics can aid in reducing concrete porosity at later ages, hence increasing concrete durability (Chao-Lung et al. 2011). RHA may also be used to minimize the cost of cement manufacturing since, like every pozzolanic material obtained as a by-product, it is less expensive than cement clinker.

Rice husk ash (RHA) has a high degree and potential application as supplementary material to cement, as well as sugarcane bagasse, and its physical properties depend on different processing conditions, such as the type of burning, grinding (type, time, process), and separation (Siddika et al. 2021; de Azevedo et al. 2022).

Physical and chemical characteristics

The chemical composition of RHA that Safari et al. (2018) reported after X-ray fluorescence (XRF) examination is presented in Table 1. It can be realized that the volumes of SiO_2 and CaO were fully opposite to each other in RHA and cement: SiO_2 was 91.94% and 19.98%, while CaO content was 1.05% and 64.73% for RHA and cement, respectively. Furthermore, the total volume of

Table 1 Chemical compositions of RHA and type I Portland cement (Safari et al. 2018)

Oxide	Percent (%)	
	Type I Portland cement	RHA
Al_2O_3	3.50	0.29
SiO_2	19.98	91.94
Fe_2O_3	4.11	0.25
CaO	64.73	1.05
SO_3	3.79	0.37
Na_2O	0.15	0.11
MgO	2.07	0.44
TiO_2	0.27	0.07
MnO	0.20	--
K_2O	0.63	1.69
LOI	0.35	2.65
Zn	--	0.45
P_2O_5	--	0.44

Table 2 Physical characteristics of OPC and RHA (Noaman et al. 2019)

Characteristics	OPC	RHA
Passed through sieve (mm)	0.075	0.075
Specific gravity (dry)	3.10	2.00
Fineness (%)	100	80
Bulk density (g/cm^3)	--	0.435

SiO_2, Al_2O_3, and Fe_2O_3 (92.49%) shows that RHA was a highly pozzolanic material according to ASTM-C618. The minimal loss of ignition ($LOI = 2.65$) in RHA indicates that it has been effectively decarburized.

Umasabor and Okovido (2018) described the chemical composition of RHA, suggesting that it is made up of compounds that have been found to have good characteristics important for high-quality concrete manufacturing. The total ratios of Fe_2O_3, SiO_2, and Al_2O_3 in RHA were 89.6%, which is greater than the minimum of 70% necessary to designate any material as pozzolan by the International Pozzolan Association (Concrete & Aggregates 2013).

Noaman et al. (2019) also reported on the usage of Los Angeles abrasion equipment for milling RHA Keertana and Gobhiga (2016). Later, RHA that had passed through a 75 µm sieve was employed for examination. Table 2 shows the fineness of RHA. According to the table, 80% of RHA went through a 75 µm sieve. As documented in previous research, the fineness of RHA rises with increasing grinding time (Al-Khalaf & Yousif 1984; Zain et al. 2011).

Fresh and hardened concrete characteristics

Padhi et al. (2018) performed slump analysis to assess the workability of recycled aggregate concrete mixtures with various RHA to reference mixtures made with naturally accessible aggregate. It was observed that the workability of natural aggregate concrete mixtures declined (62–52 mm) when 20% cement was replaced with RHA, and it declined to 40 mm when 35% cement was replaced with RHA. This decrease in workability with the addition of RHA to concrete might be attributed to RHA's increased fineness, which makes it a more absorbent material than cement. Yuzer et al. (2013) analyzed the concrete varieties in which RHA replaced 0–5% by value of cement. It was reported that the introduction of RH lessened the density of concrete.

He et al. (2017) stated that pure uniaxial compression was used to assess the compressive strength. The compressive strength rose as the RHA concentration increased. The rate of growth, however, decreases when the RHA-to-binder ratio exceeds 15%. According to Gill and Siddique (2018), the compressive strength of the concrete mixtures containing RHA was greater than that of the reference specimen. This gain in strength can be attributed to the use of RHA.

Wei and Meyer (2016) demonstrated that a small percent replacement of cement by RHA improved the flexural strength and durability of fiber-reinforced cementitious products when exposed to wetting and drying phases, due to the high pozzolanic activity of RHA is attributed to its silicate content which is comparable to silica fume, and the large specific surface area due to its unique pore structure. Chopra et al. (2015) also reported similar findings. Mohseni et al. (2016) observed a loss in 28-day flexural strength of 2, 10, and 15% when RHA replaced 10, 20, and 30% of the cement, respectively. Flexural strength was measured at 90 days. Whenever 3% nano-Al_2O_3 was added as a partial substitute by weight of the cement to a mixture containing 10% RHA, flexural strength increased by 34 and 41% at 28 and 90 days, respectively.

According to Ameri et al. (2019), the addition of RHA in cement mixtures up to a particular proportion as a partial cement replacement has a favorable influence on concrete flexure strength. They discovered that concrete with 15% RHA had the highest flexural strength, which was 21% higher than a reference mixture having 0% RHA. Previous research has found that integrating bacterial cells and RHA as a partial substitute for cement increases the flexural strength of the concrete (Salas et al. 2009; Meera et al. 2016; Mohseni et al. 2016; Wei & Meyer 2016).

According to Madandoust et al. (2011), the split tensile strength of reference concrete was larger than that of concrete mixtures containing 5% RHA and 10% glass powder by weight of cement. The stated strength of the concrete mixtures was 71% of that of conventional concrete after 7 days and 97% after 90 days. Venkatanarayanan and Rangaraju (2015) observed an improvement in strength comparable to that of reference concrete mixtures when RHA was utilized to substitute 7.5 and 15% of the cement in concrete mixtures by weight. When unground RHA was required, the development was 16 and 4%, respectively, whereas ground RHA was 21 and 15%.

Ameri et al. (2019) reported that using 15% RHA as a partial substitute for cement resulted in a peak modulus of elasticity (MOE) that was 14% higher than that of RC. Venkatanarayanan and Rangaraju (2015) discovered that the MOE of concrete with varying degrees of RHA increased by 9–16% when compared to the reference concrete. The increase in MOE can be attributed to pore refinement caused by RHA's micro filling action and the generation of fresh CSH gel (Siddique et al. 2016).

Durability characteristics of concrete containing RHA

Padhi et al. (2018) indicated that increasing the replacement proportion of RHA with cement from 0 to 35% improved the water absorption of conventional concrete mixtures by 5.55–7.21%. The same results were obtained for a concrete mixture that contained 100% of recycled coarse aggregate (RCA) (Tayeh et al. 2021a). This rise in water absorption can be linked to higher RHA water absorption (Agwa et al. 2020). This increased water absorption shows that both natural coarse aggregate (NCA) and RCA concrete mixtures are less durable. RHA has a lower alumina percentage and a higher silica content, which contributes to the improved outcomes of RHA-based mixtures (Kannan & Ganesan 2014). Kannan and Ganesan (2014) tested the sulfate resistance of several mixtures by exposing them to a 5% solution of sulphuric acid. They discovered that self-compacting concrete (SCC) created with RHA was more resistant to acid assault than SCC produced without RHA.

According to Koushkbaghi et al. (2019), the addition of RHA in concrete mixes significantly reduced the diffusivity of chloride ions; all combinations with RHA replacements had a lower diffusion coefficient than the reference mixtures. The lower diffusion coefficient of the concrete with RHA infusions might be attributed to finer pore development and lower porosity of the concrete. The RHA, through the secondary hydrolysis reaction, aids in the generation of a greater volume of CSH gel than the reference mixtures, which purifies the pore development of concrete.

According to Kwan and Wong (2020), concrete is vulnerable to acid attacks and can be subjected to acids as a result of acid deposition or flowing industrial wastewater. Chemical impact on concrete can promote the dissolution of the concrete binder phase and, if not addressed, can cause chronic deterioration of the concrete as a result of extended exposure to harmful chemicals.

Concrete with RHA replacement has been shown to have less mass reduction and strength decline when compared to concrete without RHA replacement. RHA increased the resilience of concrete to the acid attack in nearly all of the mixtures. This might be attributed to the RHA concrete's decreased calcium hydroxide concentration (Chang et al. 2005). Moreover, Table 3 presents a summary of the fresh, hardened, and durability characteristics of RHA.

Olive stone biomass ash (OBA)

As a consequence of many environmental problems, it was inevitable to search for renewable resources as alternatives, and it can be concluded through previous experiences and research that the use of olive biomass ash (OBA) contributes effectively to decreasing environmental risks while at the same time positively affects the strength and characteristics of concrete. de Moraes Pinheiro et al. (2018) reported that OBA is formed in the form of a by-product or residual ash at the bottom of the furnace when olive stones are burnt to produce heat energy. The obtained ash is then dried at 105 °C for 24 h and grounded in a ball mill to homogenize and pulverize the material. It has been observed that increasing the fineness of OBA increases its dissolution rate in water.

Physical and chemical characteristics

Nogales et al. (2011) reported a 4.15% moisture content for OBA. Weight loss was also measured by calcination of the specimen of grain size 150 μm at 950 °C and it was reported to be 25.5%. A significant quantity of unburnt content in the ash was also observed. The results indicate that a reduction in volume may occur if ash is incorporated into clay material at an unsuitable heating rate. This volume reduction would lead to sample deformation or breakage through sintering. OBA's alkalinity is claimed to be $pH = 9.5$, owing to its bicarbonate, carbonate, and hydroxide concentrations.

Eliche-Quesada and Leite-Costa (2016) reported a large range of particle sizes present in OBA after completing the particle size distribution analysis. They suggested that OBA be sieved and subjected to additional particle separation processes before being employed for a specific purpose. According to their findings, 32.5% of the whole specimen may be classified as tiny particles, having gone through filter no. 400. A total of 61.5% of the samples were well-graded material with mostly sand-sized particles. It was thus discovered that particle size must be homogenized to achieve particles of 150 μm via sieving.

Font et al. (2017) characterized OBA using X-ray diffraction (XRD), X-ray fluorescence (XRF), particle size distribution, and field emission scanning electron microscopy (FESEM). They also tested pH in deionized water. OBA displayed high alkalinity in a water suspension with a value of

Table 3 A summary of fresh, hardened, and durability characteristics of RHA

The property	The effect of RHA on the property	Ref
Workability	Decreasing	Padhi et al. (2018)
	Decreasing	Chopra et al. (2015)
	Decreasing	Kannan and Ganesan (2014)
	Decreasing	Memon et al. (2011)
Density	Decreasing	Yuzer et al. (2013)
	Decreasing	Hamzeh et al. (2013)
	Decreasing	Padhi et al. (2018)
Compressive strength	Increasing	He et al. (2017)
	Increasing	Faried et al. (2021b)
	Increasing	Gill and Siddique (2018)
	Increasing	Singh et al. (2020)
	Increasing	Rumman et al. (2020)
	Increasing	Kwan and Wong (2020)
	Increasing to 10% of RHA and decreasing after this percentage	Chetan and Aravindan (2020)
	Decreasing	Hamada et al. (2021)
	Decreasing	Sua-iam and Makul (2013)
Flexural strength	Increasing	Wei and Meyer (2016)
	Increasing	Mohseni et al. (2016)
	Increasing	Faried et al. (2021a)
	Increasing	Ameri et al. (2019)
	Decreasing	Padhi et al. (2018)
Splitting tensile strength	Increasing	Panda et al. (2020)
	Negligible adverse effect	Koushkbaghi et al. (2019)
	Increases up to 10% replacement of RHA	Meddah et al. (2020)
	Negligible adverse effect	Thomas (2018)
	Increasing	Faried et al. (2021a)
Modulus of Elasticity	Increasing	Venkatanarayanan and Rangaraju (2015)
Water absorption	Developing	Padhi et al. (2018)
Sulfate resistance	Developing	Kannan and Ganesan (2014)
Chloride resistance	Developing	Koushkbaghi et al. (2019)
Acid attacks resistance	Developing	Kwan and Wong (2020)

13.5 for an OBA-water ratio of 0.47. The mean particle size of the sample was 20.1 µm, while D90, which is a 90%-passing diameter, was reported to be 45.2 µm. XRD analysis revealed the following major crystalline phases: calcite ($CaCO_3$), anorthite ($CaAl_2Si_2O_8$), portlandite ($Ca(OH)_2$), and kalicinite ($KHCO_3$). In another study, Barreca and Fichera (2013) concluded that olive stone had a moisture content of 23.67% with a particle size ranging between 1 and 6 mm. There were no traces of impurities or dust found in the sample that had a bulk density of 6399.4 N m^{-3}.

Fresh and hardened concrete characteristics

Alkheder et al. (2016) stated that as the amount of partial substitution of cement with OBA in concrete mixtures grew, so did the first setting time. They ascribed this to a slow rate of hydration caused by the cement paste's low C_3S and C_3A concentrations. However, the ultimate setting time for combination cement paste is significantly longer than for standard cement paste. This demonstrates that mixed concretes containing OBA become less resistant to cracking, which can be related to the high MgO and free CaO concentration.

Aburawi and Al-Madanib (2018) described that the initial and final setting times of cement mortar prepared with partial replacement of cement with OBA can be reduced significantly by increasing the burning time of olive stone from 6 to 8 h. The initial and final setting times with 8 h of burning were reported to be 485 min and 540 min, respectively, compared with an initial setting time of 555 min and a final setting time of 675 min achieved with 6 h of burning. This increase in burring time increases the particle surface area of OBA, resulting in enhanced particle reactivity.

Al-Akhras and Abdulwahid (2010) claimed that during the inspection, the fresh mortar was placed in two layers in a steel open-cone mould, each layer being compacted with 20 strokes, and the table was tumbled 25 times inside (15 s). Using a standard caliper, the flow value was calculated as the mean diameter of the fresh mortar. The flow table test was used to assess the workability of the olive waste ash (OWA) fresh mortar. The results revealed that the workability of the mortar decreased as the OWA concentration increased. When OWA was employed as a substitute for sand in mortar mixtures, the fresh mortar became exceedingly stiff, and an extra plasticizer was added to make workable mortar. The use of OWA in mortar mixtures reduces workability due to the greater surface area of OWA particles compared to cement or sand.

Alkheder et al. (2016) conducted a soundness experiment and discovered that the expansion of cement paste made with OWA as a substitute for cement was much lower than that of cement paste created only with OPC. It was also discovered that the decline in expansion improved as the OWA component in cement pastes rose. Again, this suggests a lower probability of cracking. This result can be attributed to the rising MgO and free CaO ratio.

Al-Akhras and Abdulwahid (2010) found that using OWA as a partial replacement for sand had a good impact on the mechanical characteristics (flexural strength and compressive strength) of mortar after 7 and 28 days of moisture-curing. It was also discovered that when OWA concentration increased, compressive strength improved. The compressive strength of mortar cured for 28 days, for example, rose from 26.5 MPa for the reference mortar to 38.2 MPa for the 15% OWA mortar. The compressive strength increased by 19, 36, 40, and 44% for OWA substitutions of 5, 10, 15, and 20%, respectively. The impact of OWA serving as a filler can be linked to the rise in compressive strength with increasing OWA concentration.

Figure 2 depicts the effect of OWA replacement of cement and sand on the mechanical characteristics of mortar containing silica sand after 28 days of wet curing. The compressive strength rose as the OWA replacement of sand increased. However, as the percentage of cement replaced by OWA grew, the compressive strength declined. This trend is warranted since the amount of cementing materials used was reduced when cement was used as a substitute. However, when replaced with sand, the OWA acts as a filler and improves the mechanical characteristics of the mortar.

Alkheder et al. (2016) partially substituted cement with OWA and tested flexural strength at 3, 7, and 28 days of curing. The flexural strength of OWA mixtures mortar in comparison with reference mortar was found to be 6–15% less (6.65 to 4.7 Mpa,respectively). This is because of reduced cement content, which causes slow hydration and high porosity in the mortar at early ages.

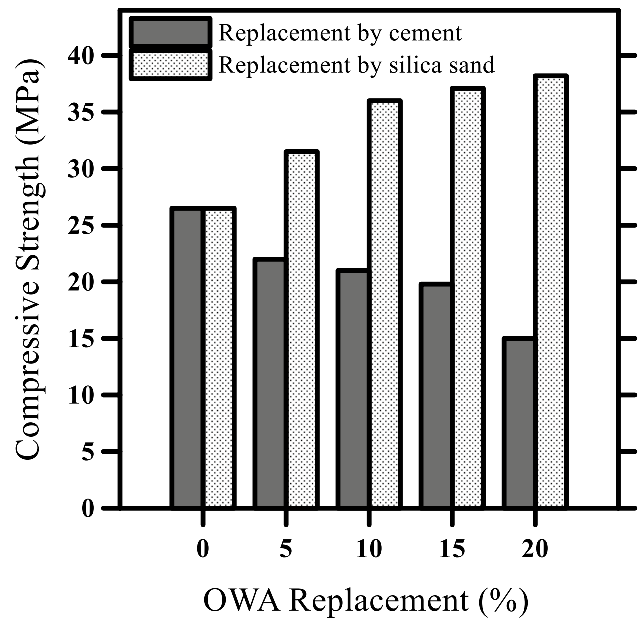

Fig. 2 Impact of OWA replacement on the compressive strength (Al-Akhras & Abdulwahid 2010)

On the other hand, the flexural strength of mortars prepared using OWA as a partial substitute for sand increased with increasing OWA content. Using OWA as a partial substitute for sand works as a filler and increases the mechanical characteristics of mortar.

Beltrán et al. (2016) reported that the porosity increased when the cement content decreased. While porosity was decreased when natural sand was substituted with biomass bottom ash (BBA). On the other hand, and as predicted, porosity gradually improved when these materials were substituted with BBA, due to the high absorption of BBA (19%). This indicates that porosity is more prone to the BBA content than the type of material replaced.

Abdulkarem et al. (2020) concluded that the density of the mixtures decreased with the increase in the content of OWA in the mixtures. This is due to the fact that the specific gravity of olive and pumice stone is less than that of sand. Typically, density was found to be inversely proportional to replacement level.

Durability characteristics of concrete containing OBA

Al-Akhras (2012) studied the impact of incorporating OWA in the mixtures on the alkali-silica reaction resistance of concrete. The results demonstrated that OWA concrete is more resistant to the alkali-silica reaction than regular concrete. The durability of OWA concrete in terms of alkali-silica reaction harm was enhanced as the proportion of OWA in the concrete mixtures increased. Alkali-silica reaction (ASR) damage was greater in concrete with a w/c rate of 0.4 than in concrete with a w/c rate of 0.5. The effects of the w/c ratio on concrete durability in terms of ASR damage are more pronounced in the presence of OWA than in the absence of OWA. Furthermore, the study determined that air-entrained concrete had greater endurance in terms of deleterious ASR than non-air-entrained concrete.

The effect of air-entrained concrete performance in terms of ASR damage is more pronounced in the presence of OWA than in the absence of OWA. To summarize, the optimal amount of OWA to be added to the concrete mixtures to achieve maximum ASR reduction is 22%. OWA concrete was also tested to increase temperatures, and it was discovered that OWA concrete performed better than the reference mixtures at elevated temperatures. Moreover, Table 4 presents a summary of the fresh, hardened, and durability characteristics of OBA.

Recycled coal bottom ash (CBA)

The CBA is a by-product produced in the burning process of various forms such as bituminous, sub-bituminous, anthracite, and lignite in thermal power plants. It shows a high pozzolanic reaction when used in concrete as supplementary cementitious material (Kim & Lee 2015). It is fine gravel to coarse sand-size material that is collected from the bottom of the boiler and is usually used as a low cost substitution material either as a replacement material in concrete mixtures or as a base material in road construction (Kurama & Kaya 2008). The disposal process of CBA has proved to be disadvantageous at this time because of the various health concerns and the increasing cost of disposal. These concerns can be eliminated through recycling and reusing the CBA in construction and other industries.

CBA is the unburned material during the coal combustion process (Oruji et al. 2019). It is produced in the boiler and consists of 10–20% of coal ash (Argiz et al. 2018). This material is a complex mixture that consists of oxides and metal carbonates (Tian et al. 2020).

Some power plants throw CBA into ponds and landfills as it is considered waste material and should be cleared (Argiz et al. 2018). However, this waste may cause environmental hazards and threats to humans if left in the open air and water (Singh & Siddique 2016).

Rafieizonooz et al. (2017) evaluated the toxicity and durability of concrete using fly ash (FA) and CBA as partial substitutes for cement and fine aggregate, respectively. The findings indicated that using FA and CBA as a partial substitute for virgin concrete components might help to minimize environmental impact, boost efficiency, and lower the cost of concrete manufacturing.

Physical and chemical characteristics

The physical properties of CBA are mainly influenced by the diversity of sources of rock. It is composed of various sources. The firing temperature of the power plant and pulverization are other factors that influence the physical characteristics of CBA. Generally, CBA particles are larger than FA particles. The density (unit weight) of CBA ranges between 1200 and 1620 kg/m^3, whereas the FA density ranges between 1900 and 2800 kg/m^3 (Zhang et al. 2019; Singh & Bhardwaj 2020). Another study reported that the specific gravity of CBA had a range between 2.36 and 3.10 (Mangi et al. 2019). When Bajare et al. (2013) investigated the characteristics of CBA as a construction material, they found that the CBA has a specific surface area of between

Table 4 A summary of fresh, hardened, and durability characteristics of concrete containing OBA

The property	The effect of OBA on the property	Ref
Setting time	Increasing	Alkheder et al. (2016)
	Decreasing (mortar)	Aburawi and Al-Madanib (2018)
Workability	Decreasing (mortar)	Al-Akhras and Abdulwahid (2010)
	Good workability	Cruz-Yusta et al. (2011)
Compressive strength	Increasing	Al-Akhras and Abdulwahid (2010)
	Decreasing	Alkheder et al. (2016)
	Decreasing	Tayeh et al. (2021b)
Flexural strength	Increasing when OWA replacement by silica sand	Al-Akhras and Abdulwahid (2010)
	Decreasing when OWA replacement by cement	
	Decreasing	Alkheder et al. (2016)
	Decreasing	Beltrán et al. (2016)
Porosity	Increasing	Beltrán et al. (2014)
	Increasing	Beltrán et al. (2016)
Hardened density	Decreasing	Abdulkarem et al. (2020)

1164 and 9849 m^2/g that was acquired after grinding CBA for 45 min.

In terms of its chemical composition, the presence of SiO_2 and Al_2O_3 in CBA as the main composites helps to achieve pozzolanic reaction, as noted in the case of fly ash (Namkane et al. 2016). These composites may react with calcium hydroxide during the cement hydration process, producing calcium silicate hydrate and calcium aluminate hydrate gels (Namkane et al. 2016).

Fresh and hardened concrete characteristics

The w/c and the characteristics of aggregates are the main reference factors that influence concrete performance. Several studies were carried out to measure the workability of normal concrete using compaction factor and slump tests. Generally, increasing the content of CBA in concrete mixtures leads to decreased slump values. Aggarwal and Siddique (2014); Remya Raju and Aboobacker (2014) stated that the presence of different cement additives decreases the slump values of concrete mixtures. The same outcomes were observed due to the use of the test of compaction factor, whereas the compaction factor values were decreased due to the increased CBA content in the concrete mixes (Jaleel & Maya 2015). In general, the particle nature of CBA led to reduced slump values in the different concrete mixtures.

Andrade et al. (2009) investigated the influence of the use of coal bottom ash as a replacement for natural fine aggregates on the properties of concrete in the fresh state. (Andrade et al. 2009) used the CBA as a fine aggregate substitution to explore the fresh concrete characteristics and observed excessive water loss by bleeding because of the high quantity of CBA in the concrete mixtures. Ghafoori and Bucholc (1996) confirmed that due to the increased request for mixture water, the CBA concrete mixtures showed a higher amount of bleeding water than the reference concrete mixtures. According to Ghafoori and Buchole (1997), bleeding water varied between 2.79 and 0.54% for a concrete mixture including both natural fine aggregates and CBA, which was somewhat higher than the reference concrete mixtures.

The initial setting time of cement paste is the period following the initial non-setting time when the concrete mixtures or cement paste begin to demonstrate a specific amount of stiffness or an increase in temperature. Some researchers studied the influence of CBA on the first setting time of cement paste and discovered that using CBA increased both the initial and final setting times when compared to the reference concrete (Andrade 2004). This occurrence is related to the presence of CBA-containing water in the concrete mixtures and cement paste used in hydration products. Also, the pH value decreases, resulting in a decrease or delay in the hydration processes of the cement paste (Ghafoori & Buchole 1997).

Topçu and Bilir (2010) studied the influence of CBA on the density of mortars with a constant amount of cement, 500 kg/m^3, and varying amounts of CBA substitution with natural fine aggregates. The density of the mortars was measured after 7 and 28 days of curing. A 3 kg/m^3 high range water reduction additive was also included in the mixtures. They observed that when CBA content increased, sample density decreased.

According to Singh and Siddique (2014b; 2014a; 2016), using CBA as a partial substitute for fine aggregate resulted in a lower 28-day compressive strength, but the 365-day compressive strength was roughly equivalent to the reference concrete samples. Previous research has shown that CBA has a detrimental influence on compressive strength development (Yüksel et al. 2007; Soman et al. 2014; Sachdeva & Khurana 2015; Ranapratap & Padmanabham 2016). Wongkeo et al. (2012) performed a study to assess the characteristics of lightweight concrete incorporating CBA as a cement substitute at various levels of substitution. The compressive strength rose with increasing CBA percentage, reaching 10.6 and 11.7 MPa for concrete mixtures containing 20 and 30% CBA, respectively. The compressive strength of the concrete mixtures including CBA at various replacement levels was somewhat improved, as was the inclusion of several types of additives (Kumar et al.; Yüksel et al. 2007; Remya Raju & Aboobacker 2014; Aanchna & Divya 2016). When 20% of typical fine particles were substituted with CBA, the compressive strength of normal weight concrete consisting of CBA and sugar Molasses was enhanced by up to 8% (Kumar et al.).

Wongkeo et al. (2012) did research on the characteristics of lightweight concrete, utilizing CBA as a cement alternative. It was discovered that when CBA concentration increased, so did flexural strength. Furthermore, when fine particles were partially replaced with CBA at a percentage of 30% or higher, flexural strength was significantly reduced as compared to reference concrete (Park et al. 2009). Furthermore, increasing the substitution level of fine aggregates with CBA to 50% resulted in a 30% drop in the flexural strength of concrete when compared to the reference mixtures (Hassan 2014; Sachdeva & Khurana 2015). Soman et al. (2014) also found that substituting fine aggregates with varying amounts of CBA led to lower flexural strength at various curing ages. For example, at 28 curing days, a minor improvement was noted when a combination of several cement additives, for example, FA and MK, as well as CBA as a fine aggregate substitute, was utilized to make the mixtures.

Previous research found that using CBA as a fine aggregate substitute improved split tensile strength at various curing ages (Soman et al. 2014; Sanjith et al. 2015). The inclusion of CBA as fine aggregate in the concrete mixtures causes secondary pozzolanic reactions that improve the interfacial transition zones and cement paste quality (Remya Raju & Aboobacker 2014; Singh & Siddique 2014a). Many tests demonstrated that the split tensile strength rose by 5 to 15% more than the reference concrete after 28 curing days with a CBA substitution level of no more than 20% (Sanjith et al. 2015; Singh et al. 2018).

Durability characteristics of CBA

According to Singh and Siddique (2014a), increasing the CBA level in concrete mixtures increases the resistance against chloride ion penetration. At all curing ages, the charge transmitted through the reference concrete was greater than that of the concrete containing CBA. Because of the pozzolanic reaction caused by the addition of CBA, the high chloride resistance of mixed concrete made with CBA may be connected with more densely structured concrete. Bertolini et al. (2004) investigated the resistance to chloride ion penetration for concrete made with CBA with a cube sample of 150 mm with a 3.5% by mass sodium chloride solution.

The Los Angeles abrasion test was utilized to assess the abrasion resistance of concrete made with CBA as a partial replacement of fine aggregate at various replacement amounts. It was revealed that all of the mixtures created using CBA as a partial substitution for fine aggregate had a greater mass loss (Yüksel et al. 2007).

The wear depth was first decreased at the lower CBA replacement level (20% of total weight), but the high replacement level did not affect the low CBA concentration in the concrete mixtures. The concrete behavior in this example is most likely due to the lower CBA replacement levels.

The porosity of concrete increased at high replacement levels of fine aggregate with CBA (more than 50%), and the crushed aggregate strength influenced the overall strength of the CBA-containing concrete. Rafieizonooz et al. (2017) investigated the effect of CBA content on acid resistance in terms of changing mass and compressive strength value decrease. They discovered that the C-S–H gels of cement hydration and pozzolanic material in the concrete mixtures interacted with a sulphuric acid solution to form calcium sulfate. The weight, compressive strength, and microstructure characteristics of CBA concrete samples after immersion in a 5% sulphuric acid solution were determined. The 28-day compressive strength ratings of all concrete mixes were lowered after submerging the concrete samples for 91 days.

It was discovered that the UPV values of concrete containing CBA rose with curing age. Acceptable UPV values were obtained at a lower CBA replacement level than at a higher CBA replacement level. When compared to the reference concrete, the values of UPV were lowered by around 5% for the higher fineness modulus values of CBA based on the concrete mixtures. In general, utilizing CBA as a fine aggregate substitute enhanced concrete quality by providing uniformity and homogeneity in concrete mixtures (Singh & Siddique 2016). Moreover, Table 5 presents a summary of the fresh, hardened, and durability characteristics of CBA.

Recycled palm oil fuel ash (POFA)

Palm oil is an important agricultural commodity in Thailand, Malaysia, Indonesia, Columbia, and Nigeria. These are the world's major palm oil producers (Zeyad et al. 2017). Muthusamy and Azzimah (2014) stated that POFA in lightweight concrete was explored, and it was determined that 20% partial substitution led to more strength than the reference mixes and that up to 50% partial substitution might be utilized for architectural reasons (Hamada et al. 2020b). These previous studies' findings emphasized the reduction of POFA when utilized in high-strength concretes (HSC), which might be attributed to mean particle size, the existence of unburned carbon in significant quantities, and greater loss of weight on combustion (LOI) of untreated POFA (Hamada et al. 2020a). Other investigators used a significant amount of processed POFA in the production of concrete and mortar. The utilization of up to 80% as a partial cement replacement and slag in alkaline-influenced concrete and mortar is noteworthy (Yusuf et al. 2014, 2015).

In addition, processed POFA has been utilized to increase the durability of concrete in a number of ways. A previous study discovered that the utilization of POFA in concrete lowered the efficiency of chloride diffusion despite the utilization of a significant number of superplasticizers when compared to using cedar peel cinders (Chindaprasirt et al. 2008). The utilization of recycled materials as concrete components are becoming increasingly common, owing to an increase in the quantity and strictness of environmental requirements. Several research has been carried out to reconnoiter the utilization of various compounds as cement replacements and partial substitutes, such as POFA, powder fuel as, and numerous other pozzolanic and fiber substances (Zeyad et al. 2016).

Physical and chemical characteristics

The mean particle size of OPC, ground-POFA (GPOFA), and ultrafine-POFA (UPOFA) are 6.80, 2.46, and 2.07 μm, respectively, with surface areas of 0.786, 1.695, and 1.776 m^2/g and computed specific gravities of 3.15, 2.50, and 2.60, respectively. As a result of the post and pre-heated milling procedures, the UPOFA has 71 and 16% fewer average particle sizes than the OPC and GPOFA, respectively. Due to the presence of the carbon component, the surface area of the GPOFA is 96.3% and 82.5% greater than that of the OPC and UPOFA, respectively (Passe-Coutrin et al. 2008; Gauden et al. 2010). The specific

Table 5 A summary of fresh, hardened, and durability characteristics of recycled CBA

The property	The effect of CBA on the property	Ref
Workability	Decreasing	Singh and Siddique (2016)
	Decreasing	Kasemchaisiri and Tangtermsirikul (2008)
	Decreasing	Bai and Basheer (2003)
	Decreasing	Siddique (2013)
Wet density	Increasing	Ghafoori and Bucholc (1997)
	Increasing	Singh and Siddique (2016)
	Increasing	Andrade et al. (2009)
Sitting time	Increasing	Kula et al. (2002)
	Increasing	Targan et al. (2002)
	Increasing	Ghafoori and Bucholc (1996)
Density	Decreasing	Hashemi et al. (2018)
	Increasing	Baite et al. (2016)
	Increasing	Rafieizonooz et al. (2016)
Compressive strength	Increasing	Lee et al. (2010)
	Increasing	Kasemchaisiri and Tangtermsirikul (2008)
	Increasing	Aswathy and Paul (2015)
	Increasing	Kumar et al. (2014)
	Decreasing	Seeni et al. (2012)
Flexural strength	Decreasing	Targan et al. (2002)
	Increasing	Kurama and Kaya (2008)
	Decreasing	Wongkeo et al. (2012)
	Increasing	Onprom et al. (2015)
Splitting tensile strength	Decreasing	Yuksel and Genç (2007)
	Increasing	Arumugam et al. (2011)
	Increasing	Aggarwal et al. (2007)
Moe	Decreasing	Topçu and Bilir (2010)
	Decreasing	Kim and Lee (2011)
	Decreasing	Singh and Siddique (2014b)
Water absorption	Increasing	Cadersa et al. (2014)
	Increasing	Singh and Siddique (2015)
	Decreasing	Singh and Siddique (2016)
Chloride ion permeability	Increasing	Sua-Iam and Makul (2015)
	Decreasing	Bilir (2012)
Ultrasonic pulse velocity	Decreasing	Hashemi et al. (2018)
	Decreasing	Rafieizonooz et al. (2016)
	Decreasing	Wongsa et al. (2016)
Sulfate resistance	Improving	Singh and Siddique (2014a)
	Improving	Ghafoori and Bucholc (1996)
Acid resistance	Improving	Khan and Ganesh (2016)

gravity of UPOFA is 6.2% higher than that of GPOFA and 22.1% lower than that of OPC (Pedersen et al. 2008). Figure 3 shows the original POFA and POFA-after heat treatment and re-milling.

POFA has a high concentration of Al_2O_3-SiO_2-Fe_2O_3. The G-POFA includes up to 19% unburned carbon, which generates a 15% loss on ignition and a 59% overall chemical composition. However, these results do not meet the equivalent ASTM C618 standard. Furthermore, heat treatment of the POFA at 500 °C for 90 min adds to an enhancement in the chemical properties of the UPOFA (Zeyad et al. 2017).

Fresh concrete characteristics

When it comes to fresh concrete characteristics, it is clear that the addition of UPOFA advances the workability of HSCx, and this benefit increases as the amount of UPOFA in the mixes increases. The increased workability might be

Fig. 3 **a** Original POFA and **b** POFA-after heat treatment and regrinding (UPOFA) (Zeyad et al. 2017)

attributed to the larger binder paste quantity of the HSCx, particularly at higher UPOFA/OPC replacement. When compared to OPC-HSC, the extra paste covers the aggregate better, fills the spaces, and acts as a lubricant for the aggregate to flow smoothly throughout the mixing process and slump test (Zeyad et al. 2017).

According to Zeyad et al. (2018), heat treatment of POFA to minimize carbon content has a favorable effect on concrete workability, retention, setting time, and strength. This was clear since HSCu had more strength than HSCg. In addition, when the UPOFA level in the concrete composition rose, so did workability retention. This is obvious in HSCu 60%, which showed 12.5% higher workability retention than HSCu 40% and HSC-OPC and 46.3% higher workability retention than HSCu 0%.

Hardened concrete characteristics

Zeyad et al. (2016) indicated that GPOFA and UPOFA may be utilized to make HSC with certain fresh concrete qualities like strength, transport, or permeability characteristics. UPOFA outperforms GPOFA in HSC because of its lower specific gravity and capacity to create more paste volume. Excess unburned carbon content in GPOFA decreases concrete consistency, impedes micro filling, and affects the percentage of hydration and pozzolanic reactions.

Zeyad et al. (2017) reported that the addition of the UPOFA in the concrete mixtures to prepare HSC could be a useful application in cases where concrete is subjected to an aggressive or corrosive environment, as the inclusion of UPOFA in the concrete mixtures helps reduce chloride penetration and increases ion migration time, which is a significant factor for corrosion initiation in reinforced concrete and thus improves the concrete service life. Moreover, Table 6 presents a summary of the fresh, hardened, and durability characteristics of POFA.

Table 6 A summary of fresh, hardened, and durability characteristics of POFA

The property	The effect of POFA on the property	Ref
Workability	Enhancing	Zeyad et al. (2017)
	Enhancing	Chandara et al. (2010)
	Decreasing	Chindaprasirt et al. (2008)
	Decreasing	N. Mohammed et al. (2014)
Compressive strength	Enhancing	Tayeh et al. (2013)
	Enhancing	Safiuddin et al. (2011)
	Enhancing	Zeyad et al. (2021a)
	Enhancing	Zeyad et al. (2021b)
	Decreasing	Hamada et al. (2021)
	Enhancing	Zeyad et al. (2017)
Durability characteristics	Enhancing	Zeyad et al. (2016)
	Enhancing	Cordeiro et al. (2009)
	Enhancing	Zeyad et al. (2017)
	Enhancing	Hamada et al. (2021)
	Enhancing	Zeyad et al. (2018)
	Enhancing	Zeyad et al. (2021b)

Conclusion

This paper presents the current studies on environmental impacts of C&D-waste and impacts of policies as well as possible solutions on sustainability issues, the physical and chemical characteristics in addition to the characteristics related to the fresh, hardened, and durability characteristics of seven alternatives. The main conclusions are as follows:

1. According to some predictions, the cement sector is responsible for 5–9% of global anthropogenic CO_2 emissions, which might rise to 12–23% by 2050.
2. The huge influence on the environment is generated by the emission of CO_2, depletion of natural resources, and the development of C&D-waste as building practices rise.
3. RHA offers a great deal of promise for usage as supplementary material in the manufacturing of compound cement.
4. According to the results, the effect of RHA enhances compressive, flexural, and split tensile strength, as well as MOE, water absorption, and resistance to sulfate, chloride, and acid attacks. RHA, on the other hand, reduces workability and density.
5. The usage of OBA helps to reduce environmental concerns while also improving the strength and other characteristics of concrete.
6. According to the results, OBA enhances compressive and flexural strength when used as a substitute for silica sand, and it also increases setting time and porosity. OBA, on the other hand, reduces hardened density while maintaining acceptable workability.
7. It may be determined that CBA enhances compressive and split tensile strength and that CBA increases wet density, setting time, and density. The usage of CBA also improves the durability of concrete.
8. Because of increasingly rigorous environmental laws, the use of recycled materials as concrete components is gaining popularity and has witnessed significant progress.
9. According to the results, the influence of POFA increases the compressive strength as well as the durability characteristics. POFA, on the other hand, reduces workability.

Recommendations

This literature presents alternate ways to environmental sustainability development related to construction materials and procedures. The following are some recommendations and ideas for further research: (1) Thorough investigation and analysis of alternative materials as a cement replacement to build sustainable concrete. (2) Research the environmental and economic implications of preparing sustainable concrete. (3) The potential use of the various methodologies outlined in this study in maritime sectors such as beach protection systems. (4) Investigate the long-term behavior of alternate cement replacement options in sustainable concrete. (5) Research and study of the consequences of subjecting sustainable concrete to fire and high temperatures. (6) Research into further real-time applications of the alternatives offered in this study. (7) Studying another alternatives such as fiber reinforced concrete incorporating zeolite and metakaolin as natural pozzolans, recyclable rubber, silica fume, and steel fibers.

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