Civil and Sustainable Urban Engineering

Review
Volume 2(2), 2022, 82-95
https://doi.org/10.53623/csue.v2i2.116

Utilization of Green Material for Concrete in Construction

Wei Sheng Choong[1], Jian Chong Chiu[1], Flavio Lopez-Martinez[2], Abdullah Alaklabi[3], Mariana Claudia Oliveira[4], Surya Dewi Puspitasari[5], Julius Adebayo[6]

[1]Department of Civil and Construction Engineering, Curtin University, CDT250, Miri 98009, Malaysia.
[2]Universidad Autonoma de San Luis Potosi, Av. Sierra Leona 550, Lomas 2a sección, San Luis Potosí, 78210, San Luis Potosi, Mexico.
[3]Department of Biology, Faculty of Science, University of Bisha, P.O. Box 551, Bisha 61922, Saudi Arabia.
[4]School of Civil Engineering, Architecture and Urbanism, University of Campinas, Rua Saturnino de Brito, 224, Campinas, São Paulo, 13083-889, Brazil.
[5]Department of Civil Engineering, The Republic of Indonesia Defense University, (Universitas Pertahanan Republik Indonesia), Komplek IPSC Sentul, Bogor, West Java, Indonesia.
[6]School of Engineering, African University of Science and Technology, Abuja, 900109, Nigeria.

*Correspondence: weishengchoong57@gmail.com

SUBMITTED: 3 September 2022; REVISED: 20 October 2022; ACCEPTED: 22 October 2022

ABSTRACT: In this modern technological era today, green materials are highly regarded as one of the most important elements when designing and conducting an environmentally sustainable construction project. The cement that is utilized in conventional concrete today is one of the culprits for the high levels of carbon dioxide generated, which is damaging to the environment. Many researchers have shown and suggested that cement substitution is a favorite technique for minimizing the generation of greenhouse gas (GHG) emissions as well as substituting unused raw materials with concrete. The concept of green concrete promotes sustainable development as it utilizes the least natural resources during production and mainly depends on recyclable waste materials as its main raw material. This paper displays the various designs of green concrete in developed countries by partially replacing cement with recyclable materials such as fly ash, demolished waste from construction sites, electronic waste, carpet fiber waste, palm oil fuel ash, and others. Green concrete endorses the innovative and sustainable use of waste aggregate and unconventional alternative materials to substitute cement within concrete. It is crucial to adopt the use of green concrete, especially in developed countries, as they have the capacity and financial strength to ensure adequate training, public awareness, further research and demonstration projects, as well as suitable standards to be applied to endorse the global application of green concrete in infrastructure projects.

KEYWORDS: Green materials; green concrete; palm oil fibre; sustainable building

1. Introduction

Concrete is one of the most crucial and common building materials in the construction industry, which dates back to 1300 BC, when concrete was invented. The properties of concrete, such as high durability, immense strength, and great mechanical properties, have allowed it to become such a useful material with a ton of applications in this technologically advanced era today. However, conventional concrete today has its limitations as it is not regarded as a sustainable product due to the raw material components utilized within the composition of the concrete are considered to be produced in a non-eco-friendly approach that causes harm to the environment. According to a study, cement, which is one of the main components within concrete, is capable of generating an estimated 5–6% of total carbon dioxide emissions globally, which leads to the occurrence of global warming [1]. For every ton of concrete, an estimate of 0.05 to 0.15 tons of carbon dioxide will be emitted. Hence, green concrete was introduced to mitigate the adverse impacts of concrete, as green concrete is considered as a more eco-friendly alternative, with green concrete generating an almost negligible amount of carbon dioxide emissions during its production stage, resulting in no harm to the environment. Green concrete substitutes the use of cement, which is one of the core compositions within concrete, with waste materials such as fly ash, demolished waste from construction sites, electronic waste, micro silica, marble powder, rice husk ash, carpet fibre waste, palm oil fuel ash, blast furnace slag, and others. Not all recycled wastes are suitable to be the substitution for cement as the recycled materials must also possess the required properties such as deformation, strength and durability [2]. Table 1 shows the most common types of green concrete materials and designs used in developed countries like the USA, Canada, Norway, UK, France, Japan, Russia, etc.

Table 1. Types of green concrete materials and designs utilized by developed countries

Green Concrete Material	Description	Country	References
Fly ash	Fly ash is created by the combustion of coal from coal-fired electricity or steam plants. Not only does it provide huge environmental benefits, it also improves concrete durability as well as minimizes net energy and GHG emissions. An estimated 70–80% of the cement can be substituted with fly ash without changing the properties of the cement. Fly ash is an abundant, economic, and cheap material which can readily substitute cement as the main component in concrete.	Australia, USA, Netherlands, UK	[3]
Demolished waste from construction site	These can be obtained through the fractions of demolished building structures. The properties of concrete will not change if they are mixed with both recycled demolition aggregate and natural aggregate.	Japan, USA, Netherlands, UK	[4-6]
Marble powder	Marble powder itself consists of heavy metals and is considered an industrial waste. Its Blaine fineness value is around 1.5 – 2 m^2/g with 90% of the particles able to pass through 50µm sieves.	USA, France, Belgium, Italy	[7,8]
Rice Husk Ash	Rice husk ash is obtained through rice milling, which is the process of separating or removing the husk and bran to obtain the edible part of the rice. Rice husk ash has an 85–90% amorphous silica content and is regarded as one of the most noteworthy substitute materials for concrete that helps minimize GHG.	China, USA	[9]
Blast Furnace Slag	Blast furnace slag is produced from the iron and steel making processes in water or steam blast furnaces. The properties of it are similar to those of cement.	Netherlands, France, USA, Singapore	[10,11]

According to several studies, green concrete also provides numerous beneficial advantages when compared to normal conventional concrete utilizing concrete as it displays higher compressive strength with a similar water-cement ratio, better thermal and fire resistance, aids in the re-use of waste materials, minimizes the structure’s dead weight, is more economically and energy efficient, and reduces the overall construction time due to recycled materials being faster produced when compared with cement-based concrete [12-14].

Consequently, the main objective of this study is to identify the various types of green concrete utilized within developed countries as well as determine whether the utilization of green concrete within developed countries is a more beneficial route than conventional concrete.

2. Materials and Methods

This article is fundamentally a literature review. It involved literature searching with journal databases consisting of Scopus, Science Direct, Springer Link, and Wiley Online. The main keywords used in the literature search were various keyword combinations such as green concrete, developed countries, utilization, properties, development, advantages, pollution, prospect, status, and environmental challenges. "Green concrete" was the specific inclusion criteria in the search engine. The keywords were either entered individually or jointly into the search engines. The selection process yielded 52 articles to be included in the review presented in Sections 1-6. The search criteria are as follows: 1) The articles must be written in English; 2) The articles must be scholarly in nature and peer-reviewed; journal articles were prioritized over conference papers or books in this review because they generally go through more stringent review processes; theses and dissertations were excluded from the review; and 3) The articles must address the aspect of green concrete development.

3. Green Concrete Development

Ordinary Portland Cement (OPC) is the primary source of CO_2 emissions and energy consumption in concrete.Hence, much research is being conducted to find a better substitute for OPC with less energy and carbon usage to prevent global warming. Currently, the development of green concrete within the developed countries has progressed very well, as most of the European countries, the USA, Singapore, and Japan are currently either using fly ash, blast furnace slag, marble powder, or demolition waste materials as aggregate within the concrete composition [15]. Since the production of concrete consumes a large amount of aggregates and the raw materials of the concrete may not be able to meet up with the progression in the demand for concrete, these developed countries have utilized various waste aggregates to not only help reduce the demand for raw materials within concrete but also re-use waste products as well as reduce the overall period and carbon footprint of concrete [16]. In China, the government there has utilized rice husk ash as a substitute for cement in concrete, as China is the biggest rice producer in the world, and the utilization of rice husk ash will help reduce waste product tremendously as well as save cost and energy [9]. Green concrete can be considered as a superior alternative to conventional concrete as it is more energy-efficient with minimal environmental impacts [17]. Nevertheless, different types of recycled aggregate material utilized will result in different properties of concrete in accordance with the physical properties of the waste aggregate and the substitution level. For example, the usage of glass wastes at a percentage composition between 10 and 25% as a substitute aggregate for concrete was found to strengthen the surface scaling as well as the freeze and thaw resistance of concrete, while any percentage higher than 25% aggregate has resulted in the mechanical properties of the concrete becoming very brittle [18].

The usage of alternative cements within concrete is also another route to producing green concrete. Currently, the utilization of calcium aluminate (CA) and calcium sulfoaluminate (CSO) cements has been identified to generate a lower amount of carbon dioxide towards the environment compared to conventional concrete [15]. CA cement was primarily developed to avert sulfate damage to concrete, yet it has been generally utilized in construction even though sulfate resistance is not a priority due to its sustainability. According to a study, it has been presented that there are other better alternatives to CA and CSO cement, but these alternative cements have a higher cost than the mainly used OPC, which has limited their usage [19].

4. Production and Current Status of Green Concrete

Green concrete production in developed countries is increasing as the construction industry sector in developed countries strives for sustainable development by using recycled waste materials to reduce carbon dioxide emissions and energy consumption while also maintaining the mechanical properties of cement for modern concrete infrastructure [20]. To ensure the green concrete has similar mechanical properties as the conventional concrete used, four crucial factors must be addressed, which are the material design composition, change of microstructure, special processing technique, and mixing of other efficient compounds. The application of these factors is currently being utilized within developed countries to achieve high quality green concrete by enhancing the properties of conventional concrete such as the tensile strength, reliability, durability, and cost as well as being eco-friendly, energy-efficient, and safe to use (Fig. 1) [21].

Figure 1. Properties of high quality of green concrete material.

In the USA and other European countries, the concrete produced is mainly substituted with recycled materials of either fly ash or blast furnace slag with a composition range of 10–50% to replace OPC within concrete [22]. However, this selected range can be tampered with depending on the desired properties of the given country, as various countries have different geographies, soil types, and weather. For the production of green concrete utilizing blast furnace slag, it is recommended to use a ratio of 1:4 for blast furnace slag to OPC, with a 0.30 water to cementitious ratio as the optimum condition [23]. Any blast furnace slag ratio greater than OPC will result in shrinkage and bleeding of the concrete [24]. In the case of China, the government there has produced green concrete utilizing a different type of substitute, which is rice husk ash, a type of agricultural waste that can be found abundantly within the country, being one of the largest producers of rice [9]. According to a study, it was found that the utilization of rice husk ash as a substitute for cement within concrete has helped improve the early tensile strength and durability of the concrete [25]. This is mainly attributed to the microstructural refinement of the concrete and the densification of the interfacial transition zone between the paste and aggregate [26,27]. Thus, it can be seen that each developed country has their own method and technique for the production of green concrete, as there are many routes to producing good quality green concrete to prevent environmental pollution as well as improve the properties of conventional concrete.

Concerning the current state of green concrete in developed countries, various studies have revealed that the sustainability and green building movement has already permeated the public consciousness as well as the construction industry [28,29]. In the USA, it is common practice to utilize chosen green rating systems certified by the government to assess and determine the sustainability of built infrastructure in order to help minimize any adverse environmental impacts from material use [28]. A great example will be the Leadership in Energy and Environmental Design (LEED) green building rating system (version 3) created and developed by the U.S. Green Building Council (USGBC), which has a sustainable category titled "Materials and Resources" that is dedicated to reducing adverse environmental impact as well as cutting down the amount of waste sent to incinerators and landfills. European countries such as France, Italy, Germany, and others, as well as Japan, are also very environmentally conscious and fully embrace a life cycle assessment approach to material selection, which is capable of providing a quantitative, balanced, and detailed evaluation of the life cycle impact of green concrete and other concrete products [30-32]. Singapore, even though it is a small island country, is one of the most developed countries in Southeast Asia and is also utilizing life cycle assessment as a grading system to evaluate the life cycle impact of green concrete and other concrete products [33]. So, it can be said that green concrete is in a very good place in developed countries, where people are very aware of how their actions affect the environment and how well the environment is doing.

4.1. Palm Oil Fuel Ash (POFA).

The palm oil industry is one of the main agro-industries in countries such as Malaysia and Thailand, producing vast quantities of waste in the form of empty fruit brunches, kennels, and fibers [34]. The by-products were then used as fuel to heat up boilers to produce electricity at a temperature of approximately 800 to 1000°C. The ash generated from this process was indicated as POFA. Using POFA in concrete provides many benefits in terms of the strength properties of concrete. According to Muthusamy [35], the substitution of POFA in concrete between 10 and 30% will result in higher concrete strength than control. Even so, at a substitution of 20%, it hits the limit of full compressive strength. An increment in the elasticity module was also noticed when POFA was replaced in concrete by 20%. The structural densification of the inner concrete has improved the concrete's performance. The increase in concrete strength with POFA may be due to the filling effect of fine ash and the pozzolanic reaction, which strengthen the bond between aggregate and hydrated cement matrix. Due to the limitation of calcium silicate hydrate, POFA has a short pozzolanic reaction time, resulting in a lower compressive strength at days 1, 3, and 7 of curing time. However, the concrete mixture with POFA would have equivalent or greater strength than standard concrete as the curing time began to rise on day 28. Calcium hydroxide ($Ca(OH_2)$) is formed during the hydration process when POFA and silica react, followed by a secondary Calcium silicate hydrate gel (CSH), which increases the strength of the concrete.The CSH gel that is made will fill the space between the aggregate and the cement, making the bond between the aggregate and the paste stronger [36].

In the meantime, it was reported that nanoPOFA particles caused cement hydration and served as fillers to optimise paste microstructure compared to microPOFA particles. The mix of POFA scale affects the efficiency of the concrete while it corresponds to the capacity of filling and increases the pozzolanic reaction. Greater strength performance can be achieved by replacing cement with up to 20% of ground POFA in concrete [37]. The compression strength, tensile splitting, and flexural strength display improved outcomes with POFA substitution. Anyhow, excess accumulation of POFA volume in concrete would result in concrete with less workability. The decrease in concrete workability was observed when POFA has a porous area, leading to an increased demand for water. The portion of POFA applied to the concrete therefore impacts the workability. Thirty percent (30%) of the substitution was measured as the appropriate amount of slump before the concrete would become porous and dry. Utilization of POFA material in concrete also provides benefits, such as a reduction in the release of heat energy. Excessive heat stored in the concrete could cause shrinkage and cracking. Cement compound hydration is an exothermic mechanism in which it produces heat because of the presence of calcium in ordinary Portland cement (OPC). Minimizing heat production could be done by controlling the amount of calcium in concrete by replacing part of the OPC with POFA [38].

The manufacturing of 10.1m median particle size d50 in POFA was more subtle in size than the standard OPC type 1 cement, which is measured at about 14.6m. The extent of POFA fineness exerts a considerable effect on the properties of concrete strength. The shape and specific gravity of POFA also influenced the water demand, further affecting the concrete strength and workability [39]. Another factor that might affect the concrete strength was the usage of super-plasticizers that could influence its workability and, ultimately, its strength properties. A study of replacing OPC with 40% of POFA has shown an improvement in concrete strength by 10.3%. Furthermore, a 24.0% increment in concrete strength was achieved by the research of Tangchirapat [40] by replacing 20% of OPC with POFA. Consequently, when POFA as cement replacement surpassed 40%, it indicated a significant decrease in concrete strength.

4.2. Rice husk ash (RHA).

RHA is a by-product which is achieved through the incineration of rice paddy husks. Approximately 78.6% of the weight is obtained as rice, broken rice and bran during paddy milling, with the remaining of the paddy obtained as 22.5% of husk [37]. During the firing process, 25 % of the husk was transformed into RHA, whereas the rest of the 75 % remained volatile. RHA has become an environmental threat due to the disproportionate amount of waste produced by the mill. RHA yields high proportions of non-crystalline silica that can be used to partly substitute concrete cement. The RHA's large specific surface area is responsible for the elevated pozzolanic reactions. The reactivity of silica content is solely dependent on the temperature of burning. By burning for 6 hours at a temperature of 700°C, 95% of silica can be produced. The microstructure of the concrete can be made denser by the addition of CSH gel, which will improve the concrete strength contributed by the active silica in large content.

It is believed by many experts that the amorphous reactive ash production is influenced by the temperature of burning. RHA is produced by burning rice husk at temperatures below 700°C because of its high pozzolanic activity and cellular microstructure [41].

Adding RHA to cement increases its natural consistency and cures time. In addition, the introduction of RHA into concrete leads to increased compressive strength and flexural resistance. RHA also decreases concrete density as opposed to standard concrete. Investigation into the compressive strength of concrete using RHA as a part substitution of OPC has led to increased water demand as well as an increase in the strength of concrete. The optimum substitution of RHA into concrete was found to be the optimum replacement out of the three experiments conducted with knowingly replacement percentages of 10, 20, and 25. Slight declination of concrete strength was detected in the 20 and 25 % replacements, whereas the control at 10% was higher after about 28 days. The optimum replacement for cement was about 20% by using ground RHA as a replacement. The study also reports that the compressive concrete strength with the addition of 20 % grounded RHA exceeds the equivalent value of the concrete control after the duration of 28 days. While grounded RHA has a higher carbon content, its resistance is very similar to that of normal concrete [42]. Concrete's compressive strength decreases by 20 to 30% after 90 days. The reasoning behind this is that the microstructure of the concrete will be improved as the pozzolanic activity tends to occur at a later time. In the meantime, the outcome for flexural strength shows a decrease of up to 2 to 14% from the initial value at 10, 20 and 30% replacement of cement with RHA. The compacted concrete microstructure with RHA strengthened bonding between increased tensile load resistance and the matrix of the cement [43].

4.3. Palm oil fibre (POF).

One of the natural fibers produced in the palm oil industry is palm oil Fiber (POF). It is mostly prevalent in countries such as Malaysia and Indonesia in Southeast Asia [37]. After the oil extraction was finished, the fibre was produced from the fruits and husks of crushed palm oil. Upon oil extraction, the palm oil fibre would usually be used to run the combustion of fuel in order to generate steam for the oil production process. POF utilization has been studied over the years in order to improve concrete strength while minimizing the issue of large volumes of POF waste dumping into landfills. POF waste has a dimension of 0.2 to 0.8 mm in diameter, 20 to 100 mm in length, and a density of 1450 kg/m3. Since the cell wall fibre is dense, it has comparable mechanical properties to coconut coir fibre, which makes it less prone to chemical reactions [38-40]. The cracking resistance of the concrete can be enhanced by using POF as an additive ingredient in the concrete. An ideal concrete reinforcement includes high lignin content as well as high tensile strength, which makes POF a great candidate. By using POF, mechanical properties such as tensile stress, fatigue, and cracking can all be improved. To improve mechanical properties, stress is transferred from the matrix to the fiber via interfacial shear. The ideal POF percentage for concrete use varies from 0.2 to 0.6 %. Above this amount, the compressive and flexural strength would be decreased. This is due to the disproportionate amount of POF present in the concrete due to disintegration and air void [37].

4.4. Recycled concrete aggregate (RCA).

Recycled Concrete Aggregate (RCA) is a recent approach to minimize waste created by demolishing old buildings. The increasing volume of construction and demolition waste

(CDW) has driven governments to search for alternative ways to reuse or utilize it. Unlike natural coarse aggregate structures, RCA is inhomogeneous in terms of its dynamic characteristics. Natural coarse aggregate is extracted from a rock, whereas RCA originates from the CDW, making it a potentially harmful substance. The strength and durability properties of concrete formed using RCA are dependent on the aggregate regarding its mortar content. The scale of the recycling aggregate affects the amount of mortar attached, as the finer the aggregate is added to it, the more mortar will be attached to it. Besides, the quality of concrete made using recycled aggregate often depends largely on the nature of the recycled aggregates and their proportion of concrete substitution [44]. The properties of natural aggregate concrete are enhanced by the implementation of aggregate recycling. A good mix of water and cement can boost the compressive strength of concrete. Incorporation of 100 % of RCA into concrete was found to yield higher concrete compressive strength compared to that of a natural aggregate (NA). The optimal replacement rate of NA with RCA was found to be at about 25 % replacement. increased strength due to the rough texture and absorption potential of the attached mortar in RCA, resulting in stronger bonding between recycled aggregate and cement paste. This shows that the concrete performance is influenced by the condition of the RCA. A study has discovered that the mixing of concrete with dry RCA will provide a higher compressive strength for the concrete than mixing the concrete with RCA that is saturated. It also appears that the concrete flexural strength will be decreased if there is excessive water content in the environment. The ultimate option to preserve concrete strength and minimise water absorption by RCA is to implement the sprinkler system to wet the RCA before using it and cover it to retain the moisture with a plastic sheet. Usage of recycled concrete aggregates brings benefits such as reduced environmental emissions, a reduced need for scarce landfill sites and the preservation of natural aggregate resources. RCA is also encouraged to be used in concrete because it can help the economy and is good for the environment [44,45].

5. Prospect and challenge of green concrete

The prospect of quality green concrete being utilized for all future infrastructure and facilities within developed countries looks very promising and achievable with regard to the current status of green concrete. This is because with the many environmental issues and irregularities occurring, especially global warming caused by the increase in GHG, the implementation of green concrete is able to help reduce the total amount of carbon dioxide emissions by an estimate of 7%, which is very beneficial towards the environment and us humans [46]. Furthermore, the production of green concrete also utilizes a much faster curing period than conventional concrete, and it also saves costs due to its use of recycled waste aggregate materials such as fly ash, blast furnace slag, marble powder, and demolished construction waste. Green concrete is also more energy efficient when compared to conventional concrete, and according to some studies, the mechanical properties of green concrete, such as tensile strength and durability, can be enhanced to be better than conventional concrete given that the composition of the green concrete is at optimum condition. However, one study has shown that demolished construction waste materials have lower strength and inferior quality when compared with conventional concrete. In my opinion and analysis, green concrete is indeed a very good prospect for the future sustainability of infrastructures and facilities as well as the environment, but more research and experiments may need to be conducted regarding the area of enhancing the mechanical properties of green concrete to ensure it is strong and safe to be built using it. Therefore, it can be deemed that the prospect of green concrete flourishing in the near future within developed countries is a very high possibility with many advantages, including being more economically and energy-efficient, more environmentally friendly, having a lower production time, and, at optimum composition levels, providing better mechanical properties than conventional concrete [12–14].

Although green concrete poses many advantages both economically and environmentally, there are some challenges that need to be overcome by developed countries if they are to truly produce quality green concrete that is strong and safe to be used. Based on a recent study by Abid [47], it has been shown that some recycled waste aggregate with denser microstructures are more vulnerable to high temperatures, which promotes spalling or cracking. It utilized demolished construction waste as the recycled aggregate, and upon the addition of steel fibres within the concrete composition, only the tensile strength and the durability of the concrete improved under high temperatures. Another problem that will be a stumbling block when implementing green concrete might be the lack of carbon policies and enforcement of these policies [20]. The realization of a reduction in all emissions for all construction projects can be achieved through a rapid scale-up of the utilization of green concrete alongside the incorporation of positive policies. According to a recent study, it was demonstrated that most of these sustainability products, especially green concrete, have not attained much commercial viability due to a lack of enforcement and promotion within developed countries as many construction industries are still wary regarding the mechanical properties of green concrete and unfamiliar with its contents [48]. In addition, the construction industry may also face problems in figuring out how to include the sustainable development concept within the construction projects implemented, which need the application of quality performance and environmentally friendly materials at economical costs [20]. According to a study, it was stated that some recycled waste aggregate lacked the tensile strength and durability of conventional concrete due to the incorrect composition being utilized, resulting in more cement having to be added to increase the mechanical properties, raising the cost of green concrete. However, other research has given different opinions on this by stating that given the correct composition is added within the green concrete, either being steel fiber or superplasticizer, the tensile strength and durability of the green concrete will be similar to or greater than that of conventional concrete [12,43,49]. The implementation of green concrete in the near future also requires detailed guidelines and affordable technologies, which are currently lacking for the efficient generation and processing of green concrete [49]. Field data and guidelines on the production of green concrete implementations are still limited, and it is hard to assess and justify whether the properties of the green concrete meet the standard as there is no actual universal guideline assessment regarding green concrete as well as a lack of durability data spanning up to more than 20 years regarding the condition of green concrete. Therefore, many challenges faced by implementing green concrete mainly come from uncertainty regarding the effectiveness of green concrete in the long run and how to assess it; lack of research knowledge; and lack of enforcement policies and guidelines regarding green concrete [50,51].

6. Other environmnetal considerations of green concrete

The main reason why green concrete is being implemented in developed countries is that it helps to reduce carbon dioxide emissions globally by up to 7%, which is the main cause of global warming [46]. Other environmental considerations which promote the utilization of green concrete within the developed countries' construction industry include durability, energy efficiency, and re-use of waste materials. Green concrete produced with the correct composition has greater resistance towards high temperatures and corrosion, which is crucial with the current condition of the environment, such as acid rain, being one of the major reasons why building corrosion is becoming more frequent [47,52]. Thus, the implementation of green concrete results in less construction material being required as it has a longer durability rate than conventional concrete, resulting in less environmental impact. Furthermore, the application of green concrete during the construction of infrastructures helps reduce the amount of energy consumed as the production of conventional concrete using OCP requires a large amount of natural gas or coal to heat it to an optimum temperature to generate OCP, while recycled waste aggregate such as fly ash or blast furnace slag mixed with OCP uses less energy [21]. Given that fly ash and blast furnace slag are considered by-products of other industrial processes, the energy consumed to create green concrete from the by-products is at a minimum. In addition, the application of green concrete also helps reduce waste products generated such as fly ash, blast furnace slag, and rice husk ash as it uses anywhere from 15–100% of these waste products depending on its desired properties [18].

7. Conclusion

The application of green concrete within the developed countries is very flexible as the composition of green concrete can utilize various recycled aggregate materials such as fly ash, blast furnace slag, demolished construction waste, rice husk ash, marble powder, and etc. The technique and approach that would be implemented to encourage green concrete within the construction industry would be different in each developed country, as it depends on the development priorities, development capacity, climate, and geography. The use of recycled waste aggregate materials in green concrete is very beneficial both economically and environmentally because it helps to reduce carbon dioxide emissions and prevent global warming; reduces the amount of heat energy required to produce green concrete; reduces total waste generated because green concrete reuses by-products of other industrial processes; and improves the durability of concrete infrastructures because green concrete is more resistant. The current status of application of green concrete within developed countries is quite good but can be further improved with more research being done on the field data of the durability of green concrete in the long run, having a detailed life cycle assessment to assess and evaluate the life cycle impact of green concrete, and having a universal guideline for the most optimum green concrete composition to be utilized globally. Currently, the lack of carbon policies, guidelines, and endorsement of green concrete from the government and knowledge and field data of green concrete in the long term are the main challenges faced to ensure that green concrete is applicable in the future for all construction infrastructures within developed countries. Hence, to inspire and motivate the application of green concrete in the construction industry within developed countries, more research, demonstration projects, and guidelines should be carried out to provide confidence to the construction industry to utilize green concrete and reduce the need for OPC. Suitable standards for green concrete should also be identified urgently, along with cross-disciplinary collaborations with the construction stakeholders to endorse the usage of green concrete in construction infrastructure. Green concrete should be heavily endorsed by the government for the construction industry due to its outstanding environmental, economic, and technical advantages. Green building practices are a critical element in developing environmentally friendly construction. Construction waste generated from construction activities may be used as a cementitious substitute, acting as a substitute for natural aggregates and as an additive to concrete to enhance its resistance to cracking. By utilizing green materials such as palm oil fuel ash, rice husk ash, recycled concrete aggregate, and palm oil fiber, waste generated from using concrete can be minimized. These waste materials can be reused as green materials for the partial substitution of natural aggregate and cement. The key concept of utilizing green materials in concrete is to make sure that the materials used in construction will not pose a health risk to the occupants and that the building is environmentally friendly. A comprehensive study must also be carried out to determine the optimal configuration of the mix for all the construction waste that will be replaced by concrete.

Acknowledgments

The authors wish to acknowledge Curtin University Malaysia for for facilitating this work. Collaboration from University of Bisha Saudi Arabia, The Republic of Indonesia Defense University (Universitas Pertahanan Republik Indonesia), African University of Science and Technology Nigeria, University of Campinas Brazil, and Universidad Autonoma de San Luis Potosi Mexico is highly appreciated.

Competing Interest

The authors declare that there is no competing interest.

References

[1] Nagarkar, V.; Padalkar, S.; Bhamre, S.; Tupe, A. (2017). Environmental Study on Green Concrete. *International Research Journal of Engineering and Technology*, *5*, 702–705. https://doi.org/10.22214/ijraset.2017.4126.

[2] Sormunen, P.; Karki, T. (2019). Recycled construction and demolition waste as a possiblesource of materials for composite manufacturing. *Journal of Building Engineering*, *24*, 100742. https://doi.org/10.1016/j.jobe.2019.100742.

[3] Sandanayake, M.; Gunasekara, C.; Law, D.; Zhang, G.; Setunge, S.; Wanjiru, D. (2020). Sustainable criterion selection framework for green building materials – an optimisation based study of fly-ash Geopolymer concrete. *Sustainable Materials and Technologies*, *25*, e00178. https://doi.org/10.1016/j.susmat.2020.e00178.

[4] Wagih, A.M.; El-Karmoty, H.Z.; Ebid, M.; Okba, S.H. (2013). Recycled construction and demolition concrete waste as aggregate for structural concrete. *HBRC Journal*, *9*, 193 – 200. https://doi.org/10.1016/j.hbrcj.2013.08.007.

[5] Oh, D.Y.; Noguchi, T.; Kitagaki, R.; Park, W.J. (2014). CO_2 emission reduction by reuse of building material waste in the Japanese cement industry. *Renewable and Sustainable Energy Reviews*, *38*, 796–810. https://doi.org/10.1016/j.rser.2014.07.036.

[6] Zhang, C.; Hu, M.; Yang, X.; Miranda-Xicotencatl, B.; Sprecher, B.; Maio, F.D.; Zhong, X.; Tukker, A. (2020). Upgrading construction and demolition waste management from downcycling to recycling in the Netherlands. *Journal of Cleaner Production*, *266*, 121718. https://doi.org/10.1016/j.jclepro.2020.121718.

[7] Arel, H.S. (2016). Recyclability of waste marble in concrete production. *Journal of Cleaner Production*, *131*, 179–188. https://doi.org/10.1016/j.jclepro.2016.05.052.

[8] Corinaldesi, V.; Moriconi, G.; Naik, T.R. (2010). Characterization of marble powder for its use in mortar and concrete. *Construction and Building Materials*, *24*, 113–117. https://doi.org/10.1016/j.conbuildmat.2009.08.013.

[9] Gursel, A.P.; Maryman, H.; Ostertag, C. (2016). A life-cycle approach to environmental, mechanical, and durability properties of "green" concrete mixes with rice husk ash. *Journal of Cleaner Production*, *112*, 823 – 836. https://doi.org/10.1016/j.jclepro.2015.06.029.

[10] Rodriguez, A.; Manso, J.M.; Aragon, A.; Gonzalez, J.J. (2009). Strength and workability of masonry mortars manufactured with ladle furnace slag. Resources, *Conservation and Recycling*, *53*, 645 – 651. https://doi.org/10.1016/j.resconrec.2009.04.015.

[11] Wesseling, J.H.; Van der Vooren, A. (2017). Lock-in of mature innovation systems: the transformation toward clean concrete in the Netherlands. *Journal of Cleaner Production*, *155*, 114 – 124. https://doi.org/10.1016/j.jclepro.2016.08.115.

[12] Khan, S.; Maheshwari, N.; Aglave, G.; Arora, R. (2020). Experimental design of green concrete and assessing its suitability as a sustainable building material. *Materials Today: Proceedings*, *26*, 1126–1130. https://doi.org/10.1016/j.matpr.2020.02.225.

[13] Li, Y.; Qiao, C.; Ni, W. (2020). Green concrete with ground granulated blast-furnace slag activated by desulfurization gypsum and electric arc furnace reducing slag. *Journal of Cleaner Production*, *269*, 122212. https://doi.org/10.1016/j.jclepro.2020.122212.

[14] Shukla, A.; Gupta, N.; Gupta, A. (2020). Development of green concrete using waste marble dust. *Materials Today: Proceedings*, *26*, 2590–2594. https://doi.org/10.1016/j.matpr.2020.02.548.

[15] Sivakrishna, A.; Adesina, A.; Awoyera, P.O.; Kumar, K.R. (2020). Green concrete: A review of recent developments. *Materials Today: Proceedings*, *27*, 54–58. https://doi.org/10.1016/j.matpr.2019.08.202.

[16] Vatannia, S.; Kearsley, E.; Mostert, D. (2020). Development of economic, practical and green ultra-high performance fiber reinforced concrete verified by particle packing model. *Case Studies in Construction Materials*, *13*, e00415. https://doi.org/10.1016/j.cscm.2020.e00415.

[17] Radonjanin, V.; Malesev, M.; Marinkovic, S.; Al Malty, A.E.S. (2013). Green recycled aggregate concrete. *Construction and Building Materials*, *47*, 1503–1511. https://doi.org/10.1016/j.conbuildmat.2013.06.076.

[18] Ismail, Z.Z.; Al-Hashmi, E.A. (2009). Recycling of waste glass as a partial replacement for fine aggregate in concrete. *Waste Management*, *29*, 655–659. https://doi.org/10.1016/j.wasman.2008.08.012.

[19] Golewski, G.L. (2018). Green concrete composite incorporating fly ash with high strength and fracture toughness. *Journal of Cleaner Production*, *172*, 218–226. https://doi.org/10.1016/j.jclepro.2017.10.065.

[20] Makul, N. (2020). Advanced smart concrete - A review of current progress, benefits and challenges. *Journal of Cleaner Production*, *274*, 122899. https://doi.org/10.1016/j.jclepro.2020.122899.

[21] Han. B.; Wang, Y.; Dong, S. (2015). Smart concretes and structures: a review. *Journal of Intelligent Material Systems and Structures*, *26*, 1303–1345. https://doi.org/10.1177/1045389X15586452.

[22] Juenger, M.C.G., Winnefeld, F., Provis, J.L., & Ideker, J.H. (2011). Advances in alternative cementitious binders. *Cement and Concrete Research*, *41*, 1232–1243. https://doi.org/10.1016/j.cemconres.2010.11.012.

[23] Chidiac, S.E.; Panesar, D.K. (2008). Evolution of mechanical properties of concrete containing ground granulated blast furnace slag and effects on the scaling resistance test at 28 days. *Cement and Concrete Composites*, *30*, 63–71. https://doi.org/10.1016/j.cemconcomp.2007.09.003.

[24] Shariq, M.; Prasad, J.; Masood, A. (2010). Effect of GGBFS on time dependent compressive strength of concrete. *Construction and Building Materials*, *24*, 1469–1478. https://doi.org/10.1016/j.conbuildmat.2010.01.007.

[25] Behnood, A.; Ziari, H. (2008). Effects of silica fume addition and water to cement ratio on the properties of high-strength concrete after exposure to high temperatures. *Cement and Concrete Composites*, *30*, 106– 12. https://doi.org/10.1016/j.cemconcomp.2007.06.003.

[26] Hasami, S.; Ahmadi, S.; Nematzadeh, M. (2014). Effects of rice husk ash and fiber on mechanical properties of pervious concrete pavement. *Construction and Building Materials*, *53*, 680 – 691. https://doi.org/10.1016/j.conbuildmat.2013.11.070.

[27] Zunino, F.; Lopez, M. (2016). Decoupling the physical and chemical effects of supplementary cementitious materials on strength and permeability: A multi-level approach. *Cement and Concrete Composites*, *65*, 19 – 28. https://doi.org/10.1016/j.cemconcomp.2015.10.003.

[28] Jin, R.; Chen, Q.; Soboyejo, A. (2015). Survey of the current status of sustainable concrete production in the U.S. *Resources, Conservation and Recycling*, *105*, 148–159. https://doi.org/10.1016/j.resconrec.2015.10.011.

[29] Jin, R., & Chen, Q. (2013). *An Investigation of Current Status of "Green" Concrete in the Construction Industry*. Paper presented at the 49th ASC Annual International Conference Proceedings, San Luis Obispo, USA.

[30] Blengini, G.A.; Garbarino, E. (2010). Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. *Journal of Cleaner Production*, *18*, 1021–1030. https://doi.org/10.1016/j.jclepro.2010.01.027.

[31] Coelho, A.; Brito, J.D. (2013). Environmental analysis of a construction and demolition waste recycling plant in Portugal – part I: energy consumption and CO_2 emissions. *Waste management*, *33*, 1258–1267. https://doi.org/10.1016/j.wasman.2013.01.025.

[32] Wittmaier, M.; Langer, S.; Sawilla, B. (2009). Possibilities and limitations of life cycle assessment (LCA) in the development of waste utilization systems – applied examples for a region in Northern Germany. *Waste Management*, *29*, 1732–1738. https://doi.org/10.1016/j.wasman.2008.11.004.

[33] Shan, X.; Zhou, J.; Chang, V.W.C.; Yang, E.H. (2017). Life cycle assessment of adoption of local recycled aggregates and green concrete in Singapore perspective. *Journal of Cleaner Production*, *164*, 918 – 926. https://doi.org/10.1016/j.jclepro.2017.07.015.

[34] Megat Johari, M.A.; Brooks, J.J.; Kabir, S.; Rivard, P. (2011). Influence of Supplementary Cementitious Materials on Engineering properties of High Strength Concrete. *Journal of Construction and Building Materials*, *25*, 2639-2648. https://doi.org/10.1016/j.conbuildmat.2010.12.013.

[35] Muthusamy, K.; Zamri, N.; Amirulkhairi, M. (2015). Engineering Effect of Mixing Ingredient on Compressive Strength of Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash. *Procedia Engineering*, *125*, 804-810. https://doi.org/10.1016/j.proeng.2015.11.142.

[36] Azrul, M.; Rajak, A.; Abdul, Z.; Ismail, M. (2015). Morphological Characteristics of Hardened Cement Pastes Incorporating Nano-Palm Oil Fuel Ash. *Procedia Manufacturing*, *2*, 512-518. https://doi.org/10.1016/j.promfg.2015.07.088.

[37] Tambichik, M.A.; Mohamad, N.; Samad, A.A.A.; Bosro, M.Z.M.; Iman, M.A. (2018). Utilization of construction and agricultural waste in Malaysia for development of Green Concrete: A Review. *IOP Conference Series: Earth and Environmental Science*, *140*, 1-9. http://doi.org/10.1088/1755-1315/140/1/012134.

[38] Awal, A.S.M.A.; Shehu, I.A. (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Journal of Fuel*, *105*, 728-731. https://doi.org/10.1016/j.fuel.2012.10.020.

[39] Chindaprasirt, P.; Homwuttiwong, S.; Jaturapitakkul, C. (2007). Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. *Construction and Building Materials*, *21*, 1492-1499. https://doi.org/10.1016/j.conbuildmat.2006.06.015.

[40] Tangchirapat, W.; Jaturapitakkul, C.; Chindaprasirt, P. (2009). Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. *Construction and Building Materials*, *23*, 2641- 2646. https://doi.org/10.1016/j.conbuildmat.2009.01.008.

[41] Karim, M.R.; Zain, M.F.M.; Jamil, M.; Lai, F.C. (2013). Fabrication of a non-cement binder using slag, palm oil fuel ash and rice husk ash with sodium hydroxide. *Journal of Construction and Building Materials*, *49*, 894–902. https://doi.org/10.1016/j.conbuildmat.2013.08.077.

[42] Ephraim, M.E.;, Akeke, G.A.; Ukpata, J.O. (2012). Compressive strength of concrete with rice husk ash as partial replacement of ordinary Portland cement. *Scholary Journal of Engineering Research*, *1*, 32–36.

[43] Jamil, M.; Khan, M.N.N.; Karim, M.R.; Kaish, A.B.M.A.; Zain. M.F.M. (2016). Physical and chemical contributions of Rice Husk Ash on the properties of mortar. *Journal of Construction and Building Materials*, *128*, 185–198. https://doi.org/10.1016/j.conbuildmat.2016.10.029.

[44] Kubissa, W.; Jaskulski, R.; Koper, A.; Szpetulski, J. (2015). Properties of Concretes with Natural Aggregate Improved by RCA Addition. *Procedia Engineering*, *108*, 30-38. https://doi.org/10.1016/j.proeng.2015.06.116.

[45] Soares, D.; Brito, J.D.; Ferreira, J.; Pacheco, J. (2014). Use of coarse recycled aggregates from precast concrete rejects: Mechanical and durability performance. *Journal of Construction and Building Materials*, *71*, 263–272. https://doi.org/10.1016/j.conbuildmat.2014.08.034.

[46] Nathaniel, O.; Mohd Sam, A.R.; Lim, N.H.A.S.; Adebisi, O.; Abdulkareem, M. (2020). Biogenic approach for concrete durability and sustainability using effective microorganisms: a review. *Construction and Building Materials*, *261*, 119664. https://doi.org/10.1016/j.conbuildmat.2020.119664.

[47] Abid, M.; Hou, X.; Zheng, W.; Waqar, G.Q. (2017). Mechanical properties of steel fiber-reinforced reactive powder concrete at high temperature and after cooling. *Procedia Engineering*, *210*, 597–604. https://doi.org/10.1016/j.proeng.2017.11.119.

[48] Lehne, J.; Prestn, F. (2018). *Making concrete change: innovation in low-carbon cement and concrete*. London, UK: Energy Environment and Resource Department.

[49] Liew, K.M.; Sojobi, A.O.; Zhang, L.W. (2017). Green concrete: prospects and challenges. *Construction and Building Materials*, *156*, 1063–1095. https://doi.org/10.1016/j.conbuildmat.2017.09.008.

[50] Duxson, P.; Provis, J.L.; Lukey, C.; Van Deventer, J.S.J. (2007). The role of inorganic polymer technology in the development of 'green concrete'. *Cement and Concrete Research*, *37*, 1590–1597. https://doi.org/10.1016/j.cemconres.2007.08.018.

[51] Gartner, E. (2004). Industrially interesting approaches to "low-CO_2" cement. *Cement and Concrete Research*, *34*, 1489 – 1498. https://doi.org/10.1016/j.cemconres.2004.01.021.

[52] Jiang, L.; He, C.; Fu, J.; Xu, D. (2019). Enhancement of wear and corrosion resistance of polyvinyl chloride/sorghum straw-based composites in cyclic sea water and acid rain conditions. *Construction and Building Materials*, *223*, 133–141. https://doi.org/10.1016/j.conbuildmat.2019.06.216.