A review on the contemporary innovations & advancements in the field of green concrete

Divyam Saran\textsuperscript{a}, Prof. Sanjeew K. Singh\textsuperscript{b}

\textsuperscript{a}College of Engineering Roorkee, School of Management, Roorkee- 247667, Uttarakhand, India
\textsuperscript{b}CSIR- Central Building Research Institute, Roorkee- 247667, Uttarakhand, India

Abstract

Waste management and environmental preservation are some of the hot topics the world is trying to address today. In the pursuit to achieve these goals, researchers and stakeholders all over the globe are researching and developing sustainable technologies. In the area of the construction industry, concrete is considered to be one of the most dynamic construction materials ever developed and utilized practically, and thus concrete is hugely utilized in construction practices all over the world. With the growing demand in infrastructure because of the increase in the global population, concrete would be needed to be produced in billions of tons. Ordinary Portland Cement (OPC) is considered to be the main binder of concrete. It leads to approximately 8% of the global carbon dioxide emission contributed by human beings. Also, the production of concrete has led to a huge danger on natural deposits of raw materials. Thus, the growing demand for concrete and its sustainability-related issues have made it critical for researchers to consider other alternatives for concrete production, where OPC and aggregates can either be partially or fully replaced as the main binding material of concrete. One such highly anticipated alternative is green concrete. The paper highlights contemporary innovations & advancements in the field of green concrete by exploring the various advantages one can achieve by utilizing alternative binding materials such as alkali-activated binders, supplementary cementitious materials, and recycled materials like wastewater in concrete. The incorporation of these alternative and more sustainable materials into concrete not only helps us to achieve the aim of green buildings and environmental conservation, but research has shown that the incorporation of these alternatives also leads to the enhanced properties of concrete as compared to the conventional one. Even if we explore the economic aspects of utilizing these alternatives, the new binders are found to be having better results than the conventional ones.

Keywords: sustainability; Ordinary Portland Cement (OPC); Supplementary cementitious materials (SCM\textsubscript{S}); Silica Fume (SF); Rice husk ash (RHA); Fly ash (FA);

1. Introduction

Research, as well as usage over a long period of time, has proved that concrete is more sustainable in comparison to its peer building materials in terms of energy consumption, and carbon emission per volume [1]. The comparison is clearly illustrated in figure 1.

![Embodied energy and carbon for various building materials](image-url)

Fig. 1. Embodied energy and carbon for various building materials [7]

But as the global population is increasing at an exponential rate (especially in India), the need for infrastructure development has also increased, which in turn calls for high-volume concrete consumption in comparison to other...
materials. As a result, the energy and carbon advantages which one used to harness from concrete are now no longer valid to that extent. The main binding material of concrete is considered to be the Ordinary Portland Cement (OPC), whose production contributes to approximately 8% of global carbon emissions, involving human beings. It also used approximately 3% of the world’s total energy [2]. Concrete is also said to be the highest consumer of fresh water and natural aggregates [3, 4], leading to the depletion of both [5, 6]. Thus, to meet the presently growing needs as well as the anticipated demands of the future, utilizing conventional methodologies wouldn’t be considered wise and successful in the longer run. Green concrete is thus very essential to be studied properly and its potential should be harnessed to the full extent to preserve natural resources and lead ways towards a cleaner environment for our future generations. The major difference between the ordinary or conventional concrete utilizing OPC & Green concrete is that the embodied energy and carbon levels of green concrete are far lower.

Green concrete necessarily incorporates waste materials as binders and aggregates. Thus, it solves the dual purpose of controlling excessive carbon emissions and energy consumption, as well as, solving the major issue of waste management.

Fig. 2. Amount of CO₂ emission per citizen in past years by countries of highest emission [56, 59]

There are various methods of developing green concrete from the conventional one. We can either partially replace OPC as the main binding material with some alternative, or we may totally replace OPC. We can utilize waste and recycled materials as a substitute for certain aggregates in concrete [8]. While we are focusing on environmentally sustainable issues, it is very important to ensure the strength and durability of the green concrete, that can resist load and various extra forces of the nature. The possibility that green concrete would be able to exhibit excellent fresh and hardened properties, which would be superior in comparison to the OPC utilizing conventional concrete would give us the benefits of the low maintenance cost, quick completion of construction projects, and extended service life. Green concrete contributes significantly towards quick completion of construction projects because the materials required to make OPC requires huge amount of coal or natural gas to heat it up to the desired temperature to obtain OPC, which in itself is a time-consuming project, whereas, fly ash can readily be obtained as a biproduct of various industrial processes, thus leading to conservation of both time and energy [66]. A number of papers are being published highlighting the current sustainability issues related to the concrete industry [9]. Our main focus in this paper would be to discuss contemporary innovations and advancements which led to the development of green concrete. The paper not only highlights the advantages of using alternative materials in concrete but also discusses the resultant effects on the properties of green concrete. This paper is hoped to help civil engineers, architects, environmental conservationists, and other stakeholders to get a review of green concrete and incorporate it in novel ways in order to achieve the aim of green and a cleaner environment. It is also expected that this paper would encourage further improvements and optimization in existing sustainable initiatives and would also lead to the development of newer and superior ones.

2. Contemporary Innovations & Advancements

One very unique thing associated with the development of green concrete is that unlike the discussion on Phase Change Materials [55], where one of the major challenges highlighted was the cost related issue because though one is achieving major energy savings and even cost savings too in the longer run, but the initial cash outflow had to be made and some economies are not yet ready to afford that initial cost. On the other side, the development of
green concrete is also involving the incorporation of other materials but they are not leading to incremental costs in the project, rather they are contributing towards overall reduced costs of concrete. R&D in the field of green concrete has been done for a very long period of time to mitigate the global issue of climate change. The R&D varies from partial to full replacement of OPC as the major binding material for concrete with alternate and sustainable materials available. These researches can either be utilized individually or in combination with other green methods, depending upon the respective need. The contemporary innovations and advancements of the past few decades are explained below.

2.1 Supplementary cementitious materials (SCMs) as partial replacement of OPC

As discussed already that the production of ordinary/ conventional cement involves the incorporation of OPC as the main binding material, whose embodied energy and carbon levels are quite high and thus not sustainable in the longer run. This calls for research in the field of alternative binding materials whose embodied energy and carbon levels are relatively low and thus could be utilized in the longer run. Now there are two ways of replacing the OPC with some alternative. First, we shall either partially replace it with some alternative or totally replace it with some alternative.

Supplementary cementitious materials (SCMs) are one of those green alternate binding materials which are successful in partially replacing OPC as the main binding material in concrete. SCM not only helps us to achieve the goal of green concrete, but they also hold the capability of enhancing the overall mechanical and durability-related properties of concrete because they possess pozzolanic and filler properties. SCM hugely contribute to waste management because they are mainly composed of waste materials from a variety of industries, and their utilization in the development of green concrete creates a useful way to harness the hidden potential behind the waste which earlier was thought as a burden for the environment. As a result, they help us to preserve several land spaces and natural deposits of raw materials which were earlier used for the disposal of the waste and also contributes towards the prevention of mining the raw material which was a necessity for OPC production respectively.

Since SCM are only being suggested as a partial replacement of OPC, thus the particular range within which this change could be made should be known very precisely, otherwise, it could lead to adverse effects on the overall health of the concrete. A range of 10-50% for SCM to replace OPC is said to be working effectively [10]. However, this range could be altered up to a limited extent only by the respective person depending upon the desired properties. In the majority of the cases, SCM is found to be utilizing their pozzolanic and filler properties in order to improve the overall properties of the resultant concrete. One of the popular examples of SCM is Silica Fume (SF) which is a by-product of ferrosilicon production. Replacement of OPC with SF within the prescribed range not only resulted in lowering the embodied energy and carbon levels but also contributed hugely towards enhancing the overall mechanical strength [11]. Another popular example of SCM is Rice Husk Ash (RHA) which is a major agricultural waste. Many agriculture-based economies were facing the issue of managing the huge quantities of RHA produced over the year. But now as RHA is contributing towards enhancing the early strength and durability of the green concrete [12], it is no longer a burden upon the government and people of the respective economy, and realizing the ultimate dream of “waste to wealth” has now become a beautiful reality. The two major attributes of densification of the interfacial transition zone (ITZ) between the paste and aggregate & refinement of the microstructure are mainly responsible for RHA being able to enhance the properties of concrete as a partial replacement of OPC [12-14]. But it should also be noted that besides all the benefits which one could derive from the usage of RHA, it poses some detrimental effects on the fresh properties of concrete. Some of the adverse effects of utilizing RHA as the partial replacement of OPC are that it leads to an increase in the water requirements and a decrease in the flowability in the concrete. Also, mechanical and durability properties can get disturbed leading to a decrease in compressive strength and increase in permeability if the replacement is not made within the adequate range. Thus, before RHA can be utilized as the partial replacement of OPC on a larger scale, initial testing on a small scale and proper optimization need to be made. The optimum replacement level of OPC with RHA is a matter of research for a long period of time because the properties of RHA vary by various reasons such as combustion conditions, location, type of fertilizer used, etc. Thus, it is of prime importance to realize that it is not enough that whichever SCM is being utilized is contributing towards achieving sustainability, their optimum replacement level needs to be pre-defined very precisely. Thus, it is advised to carry out small tests on a smaller scale so that if any discrepancies occur in the experiment results, it wouldn’t lead to much wastage of resources, and rectification towards the correction of optimum replacement levels could be made. Then only this technology would be ready to be launched and utilized on a larger scale. Coal burning is a major source of power.
generation in many parts of the globe still today and the fly ash (FA) produced from such generation is also reported to be highly efficient in further improving the properties of concrete [15, 16]. Table 1 depicts various materials one can obtain by carrying out combustion of coal at different temperature points, giving us different materials, which could be researched and if found suitable, utilized in the development of green concrete. But still, in order to achieve maximum benefits of enhanced properties and defining proper replacement levels, particular methods have to be adopted [17, 18]. Defining optimum replacement levels is highly important because in any case if FA is being utilized at high replacement level than the prescribed ones, then certain adverse effects could occur such as longer set time, lower early age strength, and slow rate of strength development. Furthermore, excessive use of FA as a partial substitute for OPC can result in durability issues such as alkali-silica reactions and scaling carbonation [19].

Table 1. Products of coal combustion depend on combustion temperature [56, 58]

| Common coal minerals | Temperatures of combustion |
|----------------------|-----------------------------|
|                      | 850°C  | 1500°C | 1800°C |
| Kaolinite            | Metakaolin | glass + mullite | Glass |
| Pyrite               | iron sulphide | hematite / magnetite | Glass |
2.2 alkali-activated binders (AABs)

Alkali-activated binders (AABs) are considered to be a very promising alternative to conventional OPC because unlike SCM, AABs could be utilized to totally replace OPC from the concrete. An example of AAB is aluminosilicate precursors, which are mainly waste produced from a variety of industrial procedures. The total replacing capability of AAB gives it a key sustainability edge over SCM. A variety of journals and other literature have reported over time that carbon dioxide emissions could be lowered as low as 80% with the incorporation of AAB instead of OPC [27]. The utilization of AAB is also solving the major issue of waste management. Aluminosilicate precursors include rice husk ash from the agricultural sector, fly ash generated as a by-product of power generation, slag from the iron sector, etc. AABs could be obtained by activating aluminosilicate precursors with an alkali medium. This leads to the dissolution of ions and the formation of a gel that ultimately hardens. Study as well as practical usage has shown that though AAB contributes significantly towards improvement in the sustainability of the concrete, certain activators may diminish this advantage. This would be the case if the embodied energy and carbon levels of the respective activators would be significantly high. Although, this difficulty could be overcome by making use of such activators whose embodied carbon and energy levels are significantly lower and their incorporation delivers similar benefits as delivered by the activators with high embodied energy and carbon levels. The types of alkali activator and aluminosilicate precursor being utilized have a major effect on determining the properties of AAB [27]. The two most common types of activators used in AAB are Sodium Hydroxide and Sodium silicate because of their resultant high strength. But the production of these two activators and even similar activators consumes a tremendous amount of energy and emits a consequential amount of carbon dioxide into the environment [28, 29]. An eco-friendly substitute for such activators is sodium carbonate which occurs naturally into the environment and its processing requires a relatively low amount of energy [30]. Thus, in order to realize the full potential behind AAB, only such activators should be utilized whose embodied energy and carbon levels are relatively lower. An improvement in mechanical and durability properties has also been seen with the use of AAB.

2.3 Alternative cements

Alternative cements are also helpful in achieving the aim of developing green concrete. Calcium sulfoaluminate (CSA) and calcium aluminate (CA) are two of the widely utilized alternative cements for the development of green concrete. Calcium aluminate is invented as early as the 100s by Jules Bied in France, and it comprises mainly of mono-calcium aluminate, and other compounds in smaller quantities [31]. It contributes towards achieving the aim of a green and clean environment as its production leads to a significantly lower amount of carbon dioxide in the environment up to 40% as compared to OPC. A major issue faced with the usage of concrete was that it earlier was unable to tolerate sulphate attacks and this issue led to the development of calcium aluminate cement. But due to its sustainable advantages, its usage has now even expanded to that parts of the globe where sulphate attacks are not a major concern. These types of cements also give us the durability advantages of improved resistance to alkali-silica reaction and improved resistance to abrasion. Additionally, their capability to rapidly gain strength makes them unique for carrying out certain types of construction.

As always advocated that the cost of a particular project should always be controlled and monitored regularly because if technology provides one with many sustainable benefits but the particular economy is not able to afford its initial cost of incorporation, then the whole technology and the R&D associated with it would be of no use. Some of the alternative cement available is quite expensive than the others and even with the OPC, which has brought a limit upon their usage despite their contribution towards promoting a sustainable and cleaner green concrete [32]. It should be noted that fly ash (FA) is found to be enhancing the overall compressive strength and toughness of cementitious composites [33].

2.4 Waste materials as aggregate in concrete

Trillions of tons of waste, whether it be in solid form or liquid form are being produced as a result of a variety of industrial processes taking place throughout the world. Now managing this waste poses a severe issue to both the residing people as well as to the environment. Thus, this calls for achieving the dream of ‘waste to wealth’. Till now, the majority of such waste is either deposited in landfills or they are left somewhere in an open area, posing
a health hazard to living beings. On the other hand, the production of concrete requires a pretty high amount of aggregates, and these aggregates are majorly derived from a number of natural sources, but it is very important to be noted that since nature has enough to fulfill one's needs but not enough for one's greed. Thus, these natural sources would soon exhaust in the near future and we wouldn’t be able to meet up our growing need for such aggregates so as to fulfill our growing demand for concrete. Thus, certain sustainable methods call for research. We need to search for some alternate materials from other sources which serve the same purpose as the conventional ones but don’t get exhausted and are readily available. Extensive R&D has shown that a variety of solid wastes could be utilized as aggregates in the concrete leading to the production of green concrete, hence eliminating the need to mine and process natural aggregates. Utilization of this solid waste not only reduces the load on natural ones but also helps in effective waste management and reducing the embodied energy and carbon levels of resultant concrete. Over a long period of time, the utilization of solid waste as aggregates into concrete has widened a lot and the list of such materials is increasing day by day. However, some of the widely used waste materials can be stated like glass [36], plastic [34], slag [38], ceramics [39], construction & demolition wastes [35], and agricultural wastes [37]. But, the resultant properties of each type of waste material incorporated into concrete differs from each other as their properties are hugely dependent upon the optimum replacement levels and physical properties of the respective aggregate. For instance, if the glass is being used in partial replacement of fine aggregates and that too in the range of 7.5-25%, then it is found to be enhancing the surface scaling and freeze & thaw resistance of concrete [40]. If the glass is being utilized at a higher proportion as aggregates in concrete, then it could lead to several detrimental effects such as a decrease in slump and reduction in mechanical properties [41].

Green concrete is considered to be one of the most energy-efficient technology [42, 43] and it also leads to much lesser detrimental effects on the environment as compared to conventional concrete and other building materials. Polymer matrices such as polypropylene and polyethylene have been also researched for use in green concrete and related composites. Polypropylene can be used to work as reinforcing fibers in concrete and polyethylene can be mainly used as aggregates. However, a marginal effect upon the workability and air permeability of concrete upon the use of polyethylene has been reported by Zehil et al [44]. The study further highlighted that usage of polyethylene beyond the recommended levels could lead to lowered strength and shrinkage of concrete. A number of alternate studies have discussed the suitability of polypropylene and polyethylene in concrete development [45-47]. Table 2. summarizes the advantages and disadvantages of incorporating some common materials into green concrete.

| Material               | Advantages / disadvantages                                                                 | Source |
|------------------------|---------------------------------------------------------------------------------------------|--------|
| Glass                  | Enhances the overall strength of concrete.                                                   | [51]   |
| Riche husk ash (powder)| Suitable for being utilized as supplementary cementitious material and alkali-activated binder. | [45]   |
| Plastic                | Enhances impact resistance of concrete and also 1% content of plastic contributes towards an increase in overall compressive strength of concrete. | [49, 50] |
| Fly ash (powder)       | Enhances the compressive strength and permeability of concrete.                             | [46, 47] |
| Polypropylene (fibrous)| Enhances the bond property of concrete but to a minimal extent only, but enhances the flexural strength of concrete to a greater extent. | [45, 53] |
| Silica fume (powder)   | Enhances the durability and strength properties of concrete but only when utilized at a level of less than 30% content. | [48]   |
Polyethylene (0-16 mm sizes) | Enhances the air permeability and overall workability of concrete at a small level, but caution needs to be taken with its use as its excessive use can lead to a major reduction in concrete strength. [52]

2.5 Wastewater

Everybody is aware today of the limited quantity of freshwater available. Even many regions around the world are facing calamities like drought due to lack of freshwater. Concrete production requires a pretty high amount of fresh water and thus it has now become quite unsustainable to produce concrete especially in regions where availability of freshwater is scarce. But at the same type, the importance of the use of water in the production of concrete cannot be simply ignored because it serves as one of the important reactants necessary to carry out the hydration reaction and it also serves as a medium for transportation of ions. Thus, it is very clear that the use of water cannot be simply eliminated from the production of concrete. Thus, researchers, as well as stakeholders, have advised utilizing wastewater instead of fresh water in the production of green concrete. This alternative will save freshwater for the necessary consumption of living beings. But, before we utilize wastewater into concrete, it, first of all, has to be treated properly because any deleterious compounds if found in the wastewater can alter the chemical reactions necessary for the proper production of concrete on a negative note.

3. Conclusions

A review of the contemporary innovations & advancements which have taken place in the field of green concrete is being presented through this paper. It is no surprise now that green concrete is highly beneficial to achieve a sustainable environment where we can control the embodied energy and carbon levels of conventional concrete [54]. Green concrete has significantly contributed towards achieving the goal of low-energy buildings and has also helped us to meet the growing demand for concrete sustainably. Thus, innovations like green concrete would aid in further development and urbanization of the world. All this is now possible in a green and clean manner. Excessive carbon emissions were posing a major threat to the people and especially children, but now with green concrete whose embodied carbon levels are relatively lower, one can control the emitted carbon into the environment and make way for a healthier and safer environment for our future generations [54]. Limited sources of energy also pose a great threat towards conventional concrete but with the recent advancements in green concrete whose embodied energy levels are relatively lower, one can now achieve the goal of low energy infrastructure.

It is known that due to urbanization at its peak, a variety of industrial processes are taking place today throughout the globe leading to the production of a substantial amount of waste for the environment. Now managing this waste was a major issue for the people because if it was left open, then it became a breeding field for a number of
diseases and if it is disposed of using landfills then it ultimately made that particular piece of land barren. Thus, the utilization of these wastes in the development of concrete is a tremendous opportunity for waste management [54].

Green concrete also provides a stronger and more durable construction material in comparison to the OPC utilizing concrete. It is also beneficial from the cost perspective as it’s a cheaper construction material that will encourage further development of infrastructure especially in developing and under-developed economies and will further contribute towards achieving the aim of low-cost housing and mass housing.

SCMs can be utilized to partially replace OPC, while AABs can be utilized to replace OPC as the binding material of concrete, but care needs to be taken while choosing and utilizing a particular activator, because only such activators should be used who have relatively lower embodied carbon and energy levels, otherwise their benefits would get nullified. Care should also be taken while partially replacing OPC with SCM because if they are not used within the recommended ranges, then it could lead to several detrimental effects on both fresh and hardened properties of concrete. If utilized optimally, it could deliver promising results and thereby reducing the overall carbon emissions leading from the production of concrete.

4. Current challenges and Scope of future research & development

Some of the challenges are being faced with the proper compliance with some standards regarding green concrete. Further research could be carried out with the aim of developing certain standards for green concrete such as determining a standard chemical composition of cements and minimum clinker concrete levels. This would lead to the stakeholders showing more confidence while adopting it, and would further enhance its range of applications throughout the globe. Another challenge that makes way for further research is the insufficient availability of durability data of up to 20 years or even more, which hinders the support and confidence among the general public while adopting green concrete. Proper differentiation among different types of green concrete such as high-strength concrete, ultra-high-strength concrete, ultra-high performance concrete, high-performance concrete, self-consolidated concrete, geopolymer concrete, lightweight concrete, and high-volume fly ash concrete, should be made for different applications. Emphasis could be made upon promoting a better understanding of the chemistry behind green concrete to create general awareness [60, 61]. The construction regulatory codes could be revised such that they become more environmentally friendly and promote the utilization of green concrete [60, 62].

Presently there is limited field data available for green concrete applications. Thus, it is required to enhance the field applications of the green concrete along with proper standardization to generate long-term data and throw some light upon their further applications [60, 63]. For the sake of civil engineers and other stakeholders, durability data upon creep, ASR, shrinkage, and abrasion should be determined correctly [60, 64].

It is further advocated by a variety of authors throughout the world to carry out R&D to develop standards because if the technology is standardized, only then it would be able to gain worldwide acceptance and deployment [60, 65]. Further R&D should be carried out towards database development which will assist towards proper manufacturing and practical utilization of green concrete [60, 65].

To create widespread awareness of this environmentally friendly and sustainable technology, hands-on training should be provided to interested people, so that they can further spread the knowledge about green concrete. Alongside such training sessions, challenges faced while practically adopting green concrete by various construction and consulting companies should be addressed adequately.

As discussed earlier, every economy around the globe is not equal in terms of finances. Thus, further research could be carried towards affordable and effective activators, so that they could also utilize green concrete to carry out sustainable development in their respective region. One novel way to enhance the field implementation of this technology is to provide incentives to the construction companies, and other organizations who wish to carry out R&D and practically apply green concrete in their respective projects.

Developing and underdeveloped economies could adopt an indigenous strategy towards manufacturing green concrete, because it would enable them to manufacture green concrete on their own, in an economical manner, and would further reduce their dependence on imported products, which are often sought to be relatively expensive.
To encourage continuous R&D and innovation in the field of green concrete as well as for other sustainable technologies, certain research clusters could be developed. Additionally, which uplifting the utilization of green concrete in construction and infrastructure development, these efforts should be coordinated to fast-track green concrete applications, prevent duplication of research, and promote the development of best practices to well establish it in the building and other construction-oriented industries on a sustainable way.

References

[1] B.V.V. Reddy, K.S. Jagadish, Embodied energy of common and alternative building materials and technologies, Energy Build. 35 (2003) 129–137. https://doi.org/10.1016/S0378-7788(01)00141-4.

[2] J.S. Damtoft, J. Lukasik, D. Herfort, D. Sorrentino, E.M. Gartner, Sustainable development and climate change initiatives, Cem. Concr. Res. 38 (2008) 115–127. https://doi.org/10.1016/j.cemconres.2007.09.008.

[3] S. Karthik, P. Rao, P. Awoyera, R. Gobinath, R. Karri, Alkalinity and strength properties of concrete containing macro silica and ground granulated blast furnace slag, IET Digit. Libr. (2018) 4.

[4] P. Murthi, P. Awoyera, P. Selvaraj, D. Dharsana, R. Gobinath, Using silica mineral waste as aggregate in a green high strength concrete: workability, strength, failure mode, and morphology assessment, Aust. J. Civ. Eng. (2018) 1–7. https://doi.org/10.1080/14488353.2018.1472539.

[5] V. Karthika, P.O. Awoyera, I.I. Akinwumi, R. Gobinath, R. Gunasekaran, N. Lokesh, Structural properties of lightweight self-compacting concrete made with pumice stone and mineral admixtures, Rev. Rom. Mater. Rom. J. Mater. 48 (2018).

[6] S. Anandaraj, J. Rooby, P.O. Awoyera, R. Gobinath, Structural distress in glass fibre-reinforced concrete under loading and exposure to aggressive environments, Constr. Build. Mater. 197 (2019) 862–870. https://doi.org/10.1016/j.conbuildmat.2018.06.090.

[7] G.P. Hammond, C.I. Jones, Embodied energy and carbon in construction materials, Proc. Inst. Civ. Eng. - Energy. 161 (2008) 87–98. https://doi.org/10.1680/ener.2008.161.2.87.

[8] P.O. Awoyera, J.O. Akinmusuru, J.M. Ndambuki, Green concrete production with ceramic wastes and laterite, Constr. Build. Mater. 117 (2016) 29–36. https://doi.org/10.1016/j.conbuildmat.2016.04.108.

[9] A. Adesina, Concrete Sustainability Issues, 38th Cem. Concr. Sci. Conf., United Kingdom, 2018.

[10] M.C.G. Juenger, F. Winnefeld, J.L. Provis, J.H. Ideker, Advances in alternative cementitious binders, Cem. Concr. Res. 41 (2011) 1232–1243. https://doi.org/10.1016/j.cemconres.2010.11.012.

[11] A. Behnood, H. Ziai, Effects of silica fume addition and water to cement ratio on the properties of high-strength concrete after exposure to high temperatures, Cem. Concr. Compos. 30 (2008) 106–112. https://doi.org/10.1016/j.cemconcomp.2007.06.003.

[12] F. Zuñino, M. Lopez, Decoupling the physical and chemical effects of supplementary cementitious materials on strength and permeability: a multi-level approach, Cem. Concr. Compos. 65 (2016) 19–28. https://doi.org/10.1016/j.cemconcomp.2015.10.003.

[13] S. Hesami, S. Ahmadi, M. Nematzadeh, Effects of rice husk ash and fiber on mechanical properties of pervious concrete pavement, Constr. Build. Mater. 53 (2014) 680–691. https://doi.org/10.1016/j.conbuildmat.2013.11.070.

[14] E. Mohseni, F. Naseri, R. Amjadi, M.M. Khotbehsara, M.M. Ranjbar, Microstructure and durability properties of cement mortars containing nano-TiO2 and rice husk ash, Constr. Build. Mater. 114 (2016) 656–664. https://doi.org/10.1016/j.conbuildmat.2016.03.136.

[15] A. Noushini, F. Aslani, A. Castel, R.I. Gilbert, B. Uy, S. Foster, Compressive stress-strain model for low-calcium fly ash-based geopolymer and heat-cured Portland cement concrete, Cem. Concr. Compos. 73 (2016) 136–146. https://doi.org/10.1016/j.cemconcomp.2016.07.004.
[16] H. Tian, Y.X. Zhang, L. Ye, C. Yang, Mechanical behaviours of green hybrid fibre-reinforced cementitious composites, Constr. Build. Mater. 95 (2015) 152–163, https://doi.org/10.1016/j.conbuildmat.2015.07.143.

[17] P. Shafigh, M.A. Nomeli, U.J. Alengaram, H. Bin Mahmud, M.Z. Jumaat, Engineering properties of lightweight aggregate concrete containing limestone powder and high volume fly ash, J. Clean. Prod. 135 (2016) 148–157, https://doi.org/10.1016/j.jclepro.2016.06.082.

[18] R. Chen, Y. Li, R. Xiang, S. Li, Effect of particle size of fly ash on the properties of lightweight insulation materials, Constr. Build. Mater. 123 (2016) 120–126, https://doi.org/10.1016/j.conbuildmat.2016.06.140.

[19] T. Madhavi, L. Raju, D. Mathur, Durability and strength properties of high volume fly ash concrete, J. Civ. Eng. Res. 4 (2014) 7–11.

[20] Ö. Çakır, F. Aköz, Effect of curing conditions on the mortars with and without GGBFS, Constr. Build. Mater. 22 (2008) 308–314, https://doi.org/10.1016/j.conbuildmat.2006.08.013.

[21] E. Özbay, M. Erdemir, H._I. Durmus, Utilization and efficiency of ground granulated blast furnace slag on concrete properties – a review, Constr. Build. Mater. 105 (2016) 423–434, https://doi.org/10.1016/j.conbuildmat.2015.12.153.

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

[23] M. Shariq, J. Prasad, A. Masood, Effect of GGBFS on time dependent compressive strength of concrete, Constr. Build. Mater. 24 (2010) 1469–1478, https://doi.org/10.1016/j.conbuildmat.2010.01.007.

[24] H.J. Yim, J.H. Kim, S.H. Han, H.-G. Kwak, Influence of Portland cement and ground-granulated blast-furnace slag on bleeding of fresh mix, Constr. Build. Mater. 80 (2015) 132–140, https://doi.org/10.1016/j.conbuildmat.2014.12.051.

[25] H.T. Le, M. Müller, K. Siewert, H.-M. Ludwig, The mix design for self-compacting high performance concrete containing various mineral admixtures, Mater. Des. 72 (2015) 51–62, https://doi.org/10.1016/j.matdes.2015.01.006.

[26] A.E. Abalaka, Strength and some durability properties of concrete containing rice husk ash produced in a charcoal incinerator at low specific surface, Int. J. Concr. Struct. Mater. 7 (2013) 287–293, https://doi.org/10.1007/s40069-013-0058-8.

[27] P. Duxson, J.L. Provis, Designing precursors for geopolymer cements, J. Am. Ceram. Soc. 91 (2008) 3864–3869, https://doi.org/10.1111/j.1551-2916.2008.02787.x.

[28] J.S.J. van Deventer, J.L. Provis, P. Duxson, D.G. Brice, Chemical research and climate change as drivers in the commercial adoption of alkali activated materials, Waste Biomass Valorization 1 (2010) 145–155, https://doi.org/10.1007/s12649-010-0015-9.

[29] G. Habert, J.B. d’Espinoso de Laacalleric, N. Roussel, An environmental evaluation of geopolymer based concrete production: reviewing current research trends, J. Clean. Prod. 19 (2011) 1229–1238, https://doi.org/10.1016/j.jclepro.2011.03.012.

[30] U.S. Geological Survey, Geological Survey Mineral Commodity Summaries: Soda Ash, 2013.

[31] K. Scrivener, A. Capmas, Calcium aluminate cements, in: P.C. Hewlett (Ed.), Lea’s Chem. Cem. Concr., Elsevier Ltd, Oxford, UK, 1998, pp. 713–782.

[32] C. Society, Calcium aluminate cements in construction: a re-assessment, 1997.

[33] G.L. Golewski, Green concrete composite incorporating fly ash with high strength and fracture toughness, J. Clean. Prod. 172 (2018) 218–226.
[34] H. Araghi, I. Nikbin, S. Reskati, E. Rahmani, H. Allahyari, An experimental investigation on the erosion resistance of concrete containing various PET particles percentages against sulfuric acid attack, Constr. Build. Mater. 77 (2015) 461–471.

[35] A. Rao, K. Jha, S. Misra, Use of aggregates from recycled construction and demolition waste in concrete, Resour. Conserv. Recycl. 50 (2007) 71–81.

[36] A. Aliabd, A. Elmoaty, A. Aboshama, Utilization of waste glass powder in the production of cement and concrete, Constr. Build. Mater. 124 (2016) 866–877.

[37] E.A. Olanipekun, K.O. Olusola, O. Ata, A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates, Build. Environ. 41 (2006) 297–301, https://doi.org/10.1016/j.buildenv.2005.01.029.

[38] A. Sivakrishna, P.O. Awoyera, S. Oshin, D. Suji, R. Gobinath, Fabrication of precast concrete slab panels incorporating foundry sand and blast furnace slag as a potential wall insulator, J. Eng. Sci. Technol. 14 (2019).

[39] Z. Ismail, E. Al-Hashmi, Recycling of waste glass as a partial replacement for fine aggregate in concrete, Waste Manage. 29 (2009) 655–659.

[40] N. Saboo, S. Shivhare, K. Kori, A. Chandrappa, Effect of fly ash and metakaolin on pervious concrete properties, Constr. Build. Mater. 223 (2019) 322–328, https://doi.org/10.1016/j.conbuildmat.2019.06.185.

[41] P. Awoyera, A. Adesina A critical review on application of alkali activated slag as a sustainable composite binder, e00268 Case Stud. Constr. Mater. (2019).

[42] N. Singh, P. Kumar, P. Goyal, Reviewing the behaviour of high volume fly ash based self compacting concrete, J. Build. Eng. 100882 (2019), https://doi.org/10.1016/j.jobe.2019.100882.

[43] A. Mehta, D.K. Ashish, Silica fume and waste glass in cement concrete production: a review, J. Build. Eng. 100888 (2019), https://doi.org/10.1016/j.jobe.2019.100888.

[44] M.S. Imbabi, C. Carrigan, S. McKenna, Trends and developments in green cement and concrete technology, Int. J. Sustainable Built Environ. 1 (2012) 194–216, https://doi.org/10.1016/j.ijsbe.2013.05.001.

[45] V. Radonjanin, M. Malešev, S. Marinkovic, A.E. Malty, Green recycled aggregate concrete, Constr. Build. Mater. 226 (2019) 1503–1511, https://doi.org/10.1016/j.conbuildmat.2019.06.076.

[46] J. Thomecroft, J. Orr, P. Savoikar, R.J. Ball, Performance of structural concrete with recycled plastic waste as a partial replacement for sand, Constr. Build. Mater. 161 (2018) 63–69, https://doi.org/10.1016/j.conbuildmat.2017.11.127.

[47] J. Thomecroft, J. Orr, P. Savoikar, R.J. Ball, Performance of structural concrete with recycled plastic waste as a partial replacement for sand, Constr. Build. Mater. 161 (2018) 63–69, https://doi.org/10.1016/j.conbuildmat.2017.11.127.

[48] N. Saboo, S. Shivhare, K. Kori, A. Chandrappa, Effect of fly ash and metakaolin on pervious concrete properties, Constr. Build. Mater. 223 (2019) 322–328, https://doi.org/10.1016/j.conbuildmat.2019.06.185.

[49] J. Thomecroft, J. Orr, P. Savoikar, R.J. Ball, Performance of structural concrete with recycled plastic waste as a partial replacement for sand, Constr. Build. Mater. 161 (2018) 63–69, https://doi.org/10.1016/j.conbuildmat.2017.11.127.

[50] A. Mehta, D.K. Ashish, Silica fume and waste glass in cement concrete production: a review, J. Build. Eng. 100888 (2019), https://doi.org/10.1016/j.jobe.2019.100888.

[51] M. Mustafa, I. Hanafi, R. Mahmoud, B. Tayeh, Effect of partial replacement of sand by plastic waste on impact resistance of concrete: experiment and simulation, Structures 20 (2019) 519–526, https://doi.org/10.1016/j.istruc.2019.06.008.
[52] A.M. Hameed, B.A. Ahmed, Employment the plastic waste to produce the light weight concrete, Energy Procedia 157 (2019) 30–38, https://doi.org/10.1016/j.egypro.2018.11.160.

[53] Z.H. Mohebi, A.B. Bahnamiri, M. Dehestani, Effect of polypropylene fibers on bond performance of reinforcing bars in high strength concrete, Constr. Build. Mater. 215 (2019) 401–409, https://doi.org/10.1016/j.conbuildmat.2019.04.230.

[54] A. Sivakrishna, A. Adesina, P. O. Awoyera et al., Green concrete: A review of recent developments, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2019.08.202

[55] Saran, D., (2021) “Phase Change Materials for Energy Efficiency in Buildings: An Overview”, paper presented at International Conference on Cutting-edge Research in Material Science and Chemistry (CRMSC-2021), organized by Department of Chemistry, Manipal University Jaipur, Rajasthan, India, 11-12 January 2021.

[56] Błaszczyński, T., & Król, M. (2015). Usage of Green Concrete Technology in Civil Engineering. Procedia Engineering, 122, 296–301. https://doi.org/10.1016/j.proeng.2015.10.039

[57] T. Błaszczyński, M. Król, Concrete and problem of carbon dioxide emission reduction, Isulations, 3 (2014), 28-30.

[58] Geopolymer Webinar, Geopolymer Institute 8-9 April 2014.

[59] Carbon Dioxide Information Analysis Center Global Carbon Budget 2014, , September 21, 2014.

[60] 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

[61] P. Duxson, J.L. Provis, G.C. Lukey, J.S. Van Deventer, The role of inorganic polymer technology in the development of ‘green concrete’, Cem. Concrr. Res. 37 (12) (2007) 1590–1597.

[62] E. Gartner, Industrially interesting approaches to “low-CO2” cements, Cement Concrr. Res. 34 (9) (2004) 1489–1498.

[63] A.R. Sakulich, Reinforced geopolymer composites for enhanced material greenness and durability, Sustainable Cities Soc. 1 (4) (2011) 195–210.

[64] R.K. Sandhu, R. Siddique, Influence of rice husk ash (RHA) on the properties of self-compacting concrete: A review, Constr. Build. Mater. 153 (2017) 751–764.

[65] D.M. Roy, Alkali-activated cements opportunities and challenges, Cem. Concrr. Res. 29 (2) (1999) 249–254.

[66] Anantha Lekshmi ML., Green concrete for the future-a review, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278- 0181, Special issue- 2016, RICESD- 2015 Conference proceedings.