Sustainable Concrete: A Review

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***Abstract*—The demand for cement and concrete is highly increasing due to urbanization and increase in the world's population. Portland cement production releases substantial amounts of greenhouse gases (GHGs) into the atmosphere, which is causing the climate change. Furthermore, cement and concrete industries consume a large amount of energy and natural resources. Therefore, it is important to develop new methods to overcome the challenges created by these products. The purpose of this paper is to make a review of opportunities for achieving sustainable cement and concrete industry. Using supplementary cementitious materials as partial replacement of cement, is one of the main opportunities to reduce the amount of cement usage in concrete. The paper also reviews other factors that can increase sustainability of cement and concrete industry, which include utilizing recycled aggregates and other recycled materials, optimize concrete mix design, structural optimization, replacement of fossil fuels, carbon capture and storage, increasing durability of concrete, extending the service life of existing infrastructures, water management, implementing regulations as well as other opportunities such as carbonation, alternative binders, energy storage and energy harvesting. These solutions can play an important role in producing more sustainable concrete and thus, reducing GHG emissions, conserving natural resources, decreasing wastes and conserving energy.**

***Index Terms*—cement, concrete, sustainability, CO_2 emission, recycle, energy**

I. Introduction

It is a known fact that with the increase of the world's population, there will be an increasing construction demand, which leads to bigger demands of natural materials. Environmental issues within construction industry will increase by depleting natural resources and burning fossil fuels.

Sustainability is balancing the relationship of environmental, social and economic matters [1]. One of the main issues within construction industry is carbon dioxide (CO_2) and other greenhouse gases (GHGs) emissions [2]. Production of Portland cement has led to 5–8% of all man-made equivalent CO_2 emission [3], which is originated from burning fossil fuels as well as calcination of limestone during the production of cement. With the increase in cement production and consumption, it is well known that releasing greenhouse gases can be more than before.

Demolition and construction, including destruction, rehabilitations and reconstruction of concrete structures are the other environmental issues causing overloading landfills, depletion of natural resources and inducing environmental costs.

Different methods to overcome the environmental challenges in cement and concrete industry are discussed in this paper.

II. Supplementary Cementitious Materials

Replacing Portland cement by other cementitious materials or additives, is one of the most effective methods in reducing greenhouse gas production. Substitution of every kilogram of cement by cementitious material reduces CO_2 emission by up to one kilogram. Fine siliceous materials in pozzolanic materials such as fly ash, ground granulated blast furnace slag, silica fume, metakaolin and rice husk ash react with calcium hydroxide at room temperature during hydration. Since such materials are all by-products of other industrial processes, there is usually no extra expenses considered for their extraction or production. Therefore, this method can play an important role in saving energy and saving irreplaceable natural resources as well as producing less greenhouse gases, which helps reducing the environmental impacts.

A. Fly Ash

Large number of thermal power plants from various parts of the world use coal as a main source of energy. During this process, huge quantities of fly ash (FA) are generated as a coal by-product of the combustion. The annual FA production from coal in the planet is about 750 million tones and there is possibility to increase in the future. In addition, FA constituents are harmful to human beings, soil as well as over- and underground water [4]. Therefore, it is vital to utilize fly ash as a cementitious material as much as possible in concrete industry to avoid such problems. Furthermore, it helps to decrease energy consumption and environmental impacts of Portland cement [5,6].

B. Silica Fume

Silica fume (SF) is highly rich in amorphous silicon dioxide (SiO2). These fine particles are byproduct of

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metallic silicon or ferrosilicon in the alloys industry [7]. High-purity quartz is reduced to silicon at 2000^{o}C temperature which delivers SiO_2 gases. Then, the SiO_2 gases are oxidized and condensed in a colder place to get 85 – 90% very fine amorphous silica that is called silica fume. The current annual production of SF is up to 1.5 million tons globally [7]. The replacement of Portland cement by silica fume in concrete production increases both the strength and durability of the concrete.

C. Ground Granulated Blast Furnace Slag

In the pig iron manufacturing, it is necessary to insert iron ore, metallurgic coke and fluxing agents in a blast furnace to obtain pig iron. The ingredients are melted in order to eliminate all the impurities. Since the pig iron melts at 1050^{o}C and slag at a much higher temperature, the pig iron melts and what is remaining in the blast furnace is only the slag, which is a by-product of the manufacturing process, or a waste material [8]. Further, for it to become ground granulated blast furnace slag (GGBFS), it necessary to water-quench the slag, and then grind it with gypsum [8]. For every ton of pig iron production, between 260 kg and 300 kg slag is produced.

It is important to note that the use of GGBFS is only adventitious if it is a waste material, otherwise its sustainability advantages are lost.

D. Metakaolin

The raw material for metakaolin is kaolin. Kaolin is a white and fine clay material that is defined as a hydrated aluminum disilicate ($Al_2Si_2O_5(OH)_4$), and it has been used for the manufacturing of ceramics for centuries. Metakaolin is therefore a product of calcinated kaolin. When the kaolinite is heated to a temperature ranging from 500oC to 800oC, it loses water by dehydroxilization. It usually contains approximately 50-55 % SiO_2 and 40 – 45% Al_2O_3, which makes it very reactive [9]. Moreover, metakaolin produces calcium silicate hydrate (CSH) gel and reacts with calcium hydroxide (CH) [10].

E. Rice Husk Ash

Rice husk ash (RHA) is a highly siliceous material produced by burning an agricultural by-product rice husk between 600 to 700^{o}C. Since RHA is a pozzolanic material with high amount of silica, it has great contribution in producing sustainable concrete. According to the environmental survey of 2002, the production of paddy rice per year was about 579.5 million tons [6], and other studies [8] reported the overall production of rice to be 745.5 million tons per year in 2016. Every 1,000 kg of rice grain gives 200 kg of rice husk and after burning, the rice husk can produce up to 20% (40 kg) of RHA. Therefore, large amount of rice husk is produced every year and it is necessary to reuse it as a supplementary cementitious material in concrete industry [6,8,11,12].

RHA has high capacity of producing concrete with high compressive strength and durability when it substitutes Portland cement in a definite portion. Based on Kishore et al. [11] there is possibility to replace Portland cement by RHA up to 50% by weight in which the compressive strength of the RHA concrete could be equal or greater than that of the Portland cement concrete both at early age and later. Moreover, the RHA concrete is more resistant against the attack of chemicals such as chlorides and sulfates.

F. Limestone Powder

The limestone manufacturing process requires low energy, since it is not heat treated unlike Portland cement. Limestone is extracted from the quarrying, and it is then crushed, separated by size and grinded to fine powder. The energy consumption in the manufacturing process of the limestone powder is mainly due to the transportation and its grinding process. [13-15].

G. Other Agricultural Wastes

Ashes from other agricultural wastes such as palm oil fuel, sugarcane bagasse and biomass wastes can also be used for this purpose. The largest oil palm producers in the world are countries like Malaysia, Indonesia, Thailand and Nigeria. The palm oil residues such as Palm bunches, palm shells and palm fiber are burnt at temperatures around 800 to 1000^{o}C in bio-diesel industry and produces palm oil fuel ash (POFA) as a byproduct. POFA can be used as a supplementary cementitious material. Based on several studies POFA works as pozzolanic material in concretes. POFA has been used up to 50% and even up to 70% as replacement for Portland cement [16-18].

Bagasse is a types of sugarcane waste that can also be used for this purpose. The combustion or firing of bagasse for boiling fuel energy purposes generates sugarcane bagasse ash. The annual worldwide production of sugarcane is about 300 million tons, which shows that a considerable amount of bagasse ash (BA) could be collected after burning the material. BA is a pozzolanic material which can replace Portland cement as a supplementary cementitious material in concrete. BA particles are mainly four times finer than Portland cement and contain a high amount of silica. BA is normally used up to 30% as replacement for Portland cement [16,17,19, 20].

Biomass combustion ash (BCA) is also another option in the Portland cement replacement as a binder in the production of sustainable concrete. The major source material of BCA is wood waste in which it is scattered all over the world in different forms. BCA obtained by collecting and burning all types of wood wastes at certain temperatures. Paris et al. [21] reported that concrete with 10 – 20% BCA achieves higher compressive strength than the normal concrete. Furthermore, the report investigates that concrete with in the mentioned range of BCA percentage has lower permeability compared to the control concrete samples. Aprianti et al. [22] reported that the optimum utilization of BCA for compressive strength is 10%. However, BCA with high amount of soluble alkalis which may lead to reaction between alkalis and silica are not beneficial to use as binders in concrete production. Usage of BCA plays positive role also in reduction of methane gas release from the wood waste which can damage the environment [21,22].

III. Recycled Concrete Aggregate (RCA)

In addition to carbon dioxide and other greenhouse gases, construction and demolition are also important issue when it comes to sustainability of cement and concrete industry. The construction and demolition waste can be used in the manufacturing of new concrete as aggregate. Aggregates makes up to approximately 75% of concrete. A big part of the concrete aggregate is coarse aggregate, therefore, it is possible to recycle old concrete and use it as coarse aggregate.

RCAs are recommended to be used as coarse aggregate, because crushed recycled concrete usually contains old cement mortar and paste, which contributes to loss of strength, workability and increase of creep and drying shrinkage [23].

The compressive strength of the concrete made from RCA will be influenced by the replacement percentage, water-to-cement ratio, amount of air content, the quality of RCA and source of the recycled concrete aggregate [24].

IV. Optimize Concrete Mix Design And Structural Optimization

Optimizing concrete mixture design is an important subject in the sustainability of concrete, because with proper aggregate packing and using additives the cement consumption can decrease and therefore less CO_2 is emitted. The cement paste's main task is to fill voids between the aggregates, to achieve a certain bind to aggregates and to achieve a certain workability for concrete. The amount of cement, water-to-binder ratio, aggregate packing, additives and admixtures are all connected to the optimization of concrete mix design.

The factor that has a great impact on the concrete's consistency is the amount of water. With an increasing amount of water in a concrete mix where everything else is unchanged, the distance between the solid particles will increase and they move more easily. However, with a lot of water in the mixture, the heaviest and largest particles can settle down, while water mixed with fine particles can accumulate on top, thus leading to bleeding [11]. Decreasing the water-to-binder ratio have a considerable impact on improving concrete's durability and diminishing concrete's bleeding. This can result is increase cement consumption, which can be avoided by using pozzolanic materials as well as fillers.

Another way to optimize concrete mix design and avoid bleeding is through aggregate packing. If the concrete has little fine aggregates and too much coarse aggregate, it leads to appear large portion of voids in concrete mix. A good distribution of aggregate size is crucial for optimizing concrete mix design. The addition of fine aggregate is crucial to stop the voids between the cement paste and the aggregates [11]

Aggregate shape also plays a great role on optimizing concrete mixture design. Rounded grain will slide easily onto one another, while angular grains tends to easily stick to each other which prevents mass movement and workability.

With proper aggregate packing it is possible to reduce the amount of cement in the concrete mix design. The role of the cement paste is to bind the aggregates together and fill voids. Therefore, by reducing voids volume between the aggregate, it is possible to reduce the amount of cement paste which is contributing to less CO_2 emissions [25].

Moreover, optimization of concrete element during the structural design can result in reduction in the element volume and thus less consumption of cement, aggregates and other concrete components.

V. Replace Fossil Fuels In Cement Production

Since the demand of cement is growing, the cement production is growing as well. As a result, there is high consumption of fossil fuels, which are not renewable and large amount of greenhouse gases emission such as CO_2 into the atmosphere. However, there are possibilities to replace fossil fuels by other energy source materials in cement production [26,27].

Utilization of waste materials as alternative fuels to replace fossil fuels is one of the most effective methods in cement production. Used tires, animal meal, refused derived fuels (RDF), solvents, used oils and biomass are some examples for alternative fuels [27].

Alternative fuels can play a considerable role on reduction of environmental impact, conservation of fossil fuels and reduction of wastes, which also indirectly reduces landfill sites. The usage of waste derived fuels in cement production have the potential to decrease the amount of disposal wastes by up to 50%. This benefits the society by diminishing the amount of waste disposals and landfill sites. Furthermore, waste derived fuels are vital in reduction of cement production costs [26].

VI. Carbon Capture And Storage

Carbon capture and storage technology is one of the practical techniques that can play a vital role in tackling the global climate change. The main task of this method is to take out the CO_2 from the cement production in cement plants and store it in underground, which can hinder it from joining the atmosphere. There are three stages in this process, which are capturing, transporting and storing of CO_2 [28,29].

The carbon capture process can be done by three different methods: pre-combustion, post-combustion and oxyfuel-combustion. Pre-combustion is removing of carbon from the fossil fuels before burning by partial oxidation of the fuels which first produces carbon monoxide (CO) and hydrogen (H_2) gases, and these gases react with steam of water (H_2O) to give CO_2 and H_2 by shift reactor. This method is widely used in chemical, gaseous fuel, fertilizers and power production. The second method is post-combustion, where the CO_2 is separated after burning of the fossil fuels. Post-combustion method is the most actual method for cement plants. In oxyfuel-combustion, fossil fuels are burned in pure oxygen rather than in air and this method can be used as post-combustion alternative [28,30,31].

A safe way of transporting CO_2 is by connecting the CO_2 capture and storage sites through pipelines. It is economically beneficial to transport high amount of CO_2 through pipelines. The quality of the pipelines (such as highly corrosion resistant), leakage detection and CO_2 compression are among the most critical aspects in CO_2 transportation.

In the last stage, it is required to have highly secured storage technology. There are various CO_2 storage options and the most common are in saline aquifers (onshore and offshore), depleted oil and gas fields. Since carbon capture and storage technology are incredibly costly and risky, more work needs to be done to reduce the costs and to make it more secured. However, this process is highly effective in reducing the environmental impacts and mitigating global climate change [28, 29, 32].

VII. Increasing Durability

Concrete durability is one of the most important properties of concrete structures. These structures have the potential to function longer without considerable degradation. Concrete with high durability plays considerable role in the reduction of raw materials, energy consumptions, wastes, greenhouse gases emissions (GHGs) and other environmental impacts related to concrete production. Highly durable concrete has high compressive strength and is more resistant to freezing, thawing, corrosion and chemical attacks such as sulfate ingress which could shortens its service life. Therefore, increasing durability of concrete is crucial in producing more sustainable concrete [7].

There are several factors that influence the compressive strength and durability of concrete. Water to cement ratio (w/c) is among the most influential to the concrete's strength and durability. Normally the w/c ratio is around 0.5, but realistically the range may be in between 0.3 and 0.8. A substantial reduction of w/c ratio increases the durability of the concrete. Concrete with w/c ratio $\leqslant 0.4$ is expected to be highly strong and more durable concrete.

The durability of concrete can be increased also by using supplementary cementitious materials in a certain proportion during concrete manufacturing. Using supplementary cementitious materials with fine particles may result in a blended concrete with very low permeability, which is crucial in increasing concrete durability.

The required concrete durability cannot be achieved without proper mix design that is balanced proportion of all the concrete constituents. Increasing durability of concrete conserves natural resources, reduces air pollution and water contamination.

VIII. Extending Service Life Of Existing Infrastructures

Although it is usually observed that concrete structures last long compared to other types of structures, there is the possibility to make them to last longer by extending the service life. The service life of existing concrete infrastructures can be extended through repairs and rehabilitation. However, good maintenance management schemes need to be in place to have more effective repairs and rehabilitation process.

Implementation of updated maintenance management system play key role in controlling and maintaining the building on the right time. With the application of clear maintenance management system, all the needed information of the structure or building can be collected without any difficulties. The system should include detailed history description and maintenance time frame of the building. The main objective of implementing maintenance management is to avoid further damages due to delaying, reduce the maintenance costs and to keep or extend the service life of the building. Every information about the building and its maintenance plan should be registered in the system's database and should be updated whenever any change has been done within the building. Therefore, it will be much easier to manage and to detect everything associated with its maintenance [33,34].

The failure of the concrete structure could be due to several reasons such as age, design fault, fire, flood, earth quack and chemical attacks. The aim of repairs and rehabilitation process is to restore the concrete to its initial effective state. With good maintenance management system and rehabilitation techniques, the service life of the existing infrastructures may be extended into several years. Based on the scientific findings, it is highly optimistic to make different concrete structures and buildings last longer than expected. Repair and rehabilitation methods not only reduces costs, but also plays important role in conserving natural resources and protecting the environment.

IX. Water Management

An important subject to sustainability of concrete, which is very little discussed, is water management. World's water resource is scarce, and the over use of this important natural resource can lead to increase more environmental problems.

Water consumption is increasing at twice the rate of global population. Moreover, the concrete production and construction are also increasing with increase in population, which requires enormous amounts of water during its process; in 2012 approximately 2 Gt of water was used in the concrete production process [35].

Water is used throughout the concrete's making process, it is used in the generation of energy to power certain manufacturing process, such as separations of aggregates, to quarry, wash the aggregates, in the process of mixing and batching and transportation. The ready-mix concrete plants consume enormous amount of water for washing out tuck mixer drums. According to Tsimas et al. [36], if the concrete truck transports around $8m^3$ of concrete, it needs 1,600 L of water to wash the truck out, which is very huge. the water discharge from the trucks are filled has alkali characteristics and has a pH of 11.5 or higher, therefore it is classified as hazardous waste from European Agency's Special Waste Regulations. This high alkali water can pollute local water sources and destroy the ecosystem.

The solutions to these issues are simple, it is important that the concrete industry start using a water cleaning system, in which they can either reuse this water for the industrial purposes or to return clean water to the nature. Water management is a topic with little focus on. It is important to bring awareness to its impacts on the nature, and what the industry can do to avoid more water wastage and nature harm.

X. Regulations and Measures

Proper regulations and measures can ensure that sustainable measures are been taken properly. It is trough regulations that the government and other institutions can ensure construction, environmental, social and economic quality. The tools such as BREEAM (British Research Establishment Environmental Assessment Method), EPD (Environmental Product declaration) can ensure quality of constructions and construction's materials.

BREEAM is point-based method that measures sustainable values in different categories.

To be able to declare the sustainability of a building it is necessary to declare how environmentally friendly a product is, and it can be measured by EPDs. EPD is based on life-cycle assessments (LCA) of environmental data from raw material withdrawal, production, use phase and disposal [37,38].

To ensure that buildings are being constructed in the right manner, to ensure people's safety and environmental safety, standards and regulations are to be followed.

Regulations is there to ensure that concrete structures are being project and dimensioned in a way that they are safer for both the environment and the society. These regulations ensure the longevity of these structures, and therefore to minimize wastes and maximize sustainability.

XI. Other Potentials

A. Carbonation

A considerable amount of the CO_2 emission from production of clinker is re-absorbed in concrete by carbonation process. The calcium hydroxide ($Ca(OH)_2$) in the hardened concrete reacts with the CO_2 absorbed from air to form calcium carbonate ($CaCO_3$) plus water.

Carbonation is highly influenced by the way concrete is handled after demolition. The effect of demolition and crushing results in higher surface area and more CO_2 uptake than before demolition. Up to about 2.4 times larger CO_2 uptake is reported by this method [39].

B. Recycling of Other Materials in Concrete

Various types of materials and wastes can be used in concrete as replacement for cement, aggregate, filler or reinforcement. Thermoset plastics, which are not easily recyclable as well as different agricultural wastes, can for example be used as aggregates or fibers in concrete. Furthermore, chars obtained from incineration or gasification of different types of wastes can be used as filler or supplementary cementitious material [40,41].

C. Alternative Binders

Binders other than Portland cement, can also bring the opportunity for moving toward sustainability. Calcined clay is one of the alternatives, which can lead to cement-based composites with lower environmental impacts. Other types of cements such as phosphate cements can also be of interest for special applications [42,43].

D. Energy Storage

Using the heat capacity of concrete can help mitigating the temperature of the indoor environment, which results in less energy consumption. Concrete can absorb the solar heat during the daytime and release this heat when the indoor environment cools down during the nighttime [44-48].

E. Energy Harvesting

The temperature gradient between the indoor- and outdoor surface of a concrete envelope can be used for harvesting energy. Although the temperature difference is not very big for this purpose, presence of large surface areas of concrete surfaces can be the reason for the reasonable potential of harvesting energy [49].

XII. Conclusion

This paper has explored different methods to increase sustainability of cement and concrete industry, with the focus on environmental issues.

Using supplementary cementitious materials, recycling concrete, optimizing the concrete mix design, structural optimization, replacing fossil fuels, CO2 capturing, increasing durability and extending the service life of existing infrastructures, water management, applying regulations, using the concrete capacity in carbonation and energy as well as using alternative binders and waste materials are among the potential approaches leading to sustainability of cement and concrete industry.

The results of different research activities have shown that, there are many opportunities to produce concrete with lower GHG emission and to preserve natural resources, diminish waste disposals and conserving energy. If these methods are introduced and followed by the cement and concrete industry it is possible to produce concrete with fewer impacts on the environment. It is important to improve concrete's sustainability to mitigate the environmental impacts due to the growing population and therefore, the increasing demand for concrete production.

References

[1] S. M. Pierre-Claude Aïtcin, *Sustainability of Concrete*, 2011, USA: Spon Press.

[2] A. A. A. Azis, et al. "Challenges faced by construction industry in accomplishing sustainability goals," in *Proc. 2012 IEEE Symposium on Business, Engineering and Industrial Applications* (ISBEIA 2012), 23-26 Sept. 2012. 2012. Piscataway, NJ, USA.

[3] J. H. Sharp, E. M. Gartner, et al. (2010). Novel cement systems (sustainability). Fred Glasser Cement Science Symposium, Advances in Cement Research.

[4] P. Kumar Sahoo, et al., “Recovery of metals and other beneficial products from coal fly ash: A sustainable approach for fly ash management,” *International Journal of Coal Science & Technology*, vol. 3, no. 3, pp. 267-283, 2016.

[5] G. L. Golewski, “Green concrete composite incorporating fly ash with high strength and fracture toughness,” *Journal of Cleaner Production*, vol. 172, pp. 218-226, 2018.

[6] G. K. Kate and S. B. Thakare, “An experimental study of high strength-high volume fly ash concrete for sustainable construction industry,” in *Proc. International Conference on Materials, Alloys and Experimental Mechanics (ICMAEM)*, 3-4 July 2017. 2017. UK: IOP Publishing.

[7] PCA, A.s.c.m.s. Cement and Concrete Applications. [cited 2018 8 & 9 February 2018]; Available from: http://www.cement.org/.

[8] E. Crossin, “The greenhouse gas implications of using ground granulated blast furnace slag as a cement substitute,” *Journal of Cleaner Production*, vol. 95, pp. 101-108, 2015.

[9] C. S. Poon, S. C. Kou, and L. Lam, “Compressive strength, chloride diffusivity and pore structure of high performance metakaolin and silica fume concrete,” *Construction and Building Materials*, vol. 20, no. 10, pp. 858-865, 2006.

[10] R. Siddique and J. Klaus, “Influence of metakaolin on the properties of mortar and concrete: A review,” *Applied Clay Science*, vol. 43, no. 3, Pp. 392-400.

[11] P. Gjerp, M. O., Sverre Smeplass, Grunnleggende betongteknologi. 1998: Byggenæringens Forlag.

[12] S. Teng, T.Y.D. Lim, and B. Sabet Divsholi, “Durability and mechanical properties of high strength concrete incorporating ultra fine Ground Granulated Blast-furnace Slag,” *Construction and Building Materials*, 2013, vol. 40, pp. 875-881.

[13] B. S. Divsholi, T. Y. D. Lim, and S. Teng, “Durability properties and microstructure of ground granulated blast furnace Slag cement concrete,” *International Journal of Concrete Structures and Materials*, vol. 8, no. 2, pp. 157-164, 2014.

[14] K. Celik, et al., “Mechanical properties, durability, and life-cycle assessment of self-consolidating concrete mixtures made with blended portland cements containing fly ash and limestone powder,” *Cement and Concrete Composites*, vol. 56, pp. 59-72, 2015.

[15] G. D. Moon, et al., “Effects of the fineness of limestone powder and cement on the hydration and strength development of PLC concrete,” *Construction and Building Materials*, 2017, vol. 135, pp. 129-136.

[16] N. Pa, N. N. A., et al,， Compressive strength of Construction Materials Containing Agricultural Crop Wastes: A Review. in 2016 International Symposium on Civil and Environmental Engineering, ISCEE 2016, December 5, 2016 - December 6, 2016. 2017. Melaka, Malaysia: EDP Sciences.

[17] J. M. Paris, et al., “A review of waste products utilized as supplements to Portland cement in concrete,” *Journal of Cleaner* Production, 2016, vol. 121, pp. 1-18.

[18] E. Aprianti, et al., “Supplementary cementitious materials origin from agricultural wastes - A review,” Construction *and Building Materials*, vol. 74, pp. 176-187, 2014.

[19] K. Ganesan, K. Rajagopal, and K. Thangavel, “Evaluation of bagasse ash as supplementary cementitious material,” *Cement and* Concrete *Composites*, vol. 29, no. 6, pp. 515-524, 2007.

[20] F. Martirena and J. Monzo, *Vegetable Ashes as Supplementary* Cementitious *Materials*, 2017.

[21] A. Hamza, S. Derogar, and C. Ince, “Utilizing waste materials to enhance mechanical and durability characteristics of concrete incorporated with silica fume,” in *Proc. 1st International Conference on Advances in Sustainable Construction Materials and Civil Engineering Systems*, ASCMCES 2017, April 18, 2017 - April 20, 2017. 2017. Sharjah, United arab emirates: EDP Sciences.

[22] O. A. Mohamed and O. F. Najm, “Compressive strength and stability of sustainable self-consolidating concrete containing fly ash, silica fume, and GGBS,” *Frontiers of Structural and Civil Engineering*, 2017, vol. 11, no. 4.

[23] K. Sakai, T. N., *The Sustainable Use of Concrete*. 2013: CRC Press.

[24] M. Tuyan, A. Mardani-Aghabaglou, and K. Ramyar, Freeze-thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate. Materials and Design, 2014. 53: p. 983-991.

[25] V. J. Per Goltermann and P. Lars, Packing of Aggregates: An Alternative Tool to Determine the Optimal Aggregate Mix. Materials Journal. 94(5).

[26] N. Chatziaras, C. S. Psomopoulos, and N. J. Themelis, “Use of waste derived fuels in cement industry: a review,” *Management of* Environmental *Quality: An International Journal*, 2016, vol. 27, no. 2, pp. 178-193.

[27] J. Karagiannis, C. Ftikos, and P. Nikolopoulos, “The use of wastes as alternative fuels in cement production,” in Fourth International Conference on Waste Management and the Environment. Waste Management IV, 2-4 June 2008. 2008. Ashurst, UK: WIT Press.

[28] N. Markusson, , et al., “A socio-technical framework for assessing the viability of carbon capture and storage technology,” *Technological Forecasting and Social Change*, vol. 79, no. 5, pp. 903-918, 2012.

[29] Z. Xian, F. Jing-Li, and W. Yi-Ming, “Technology roadmap study on carbon capture, utilization and storage in China,” *Energy* Policy, vol. 59, pp. 536-550, 2013.

[30] E. S. Rubin, et al., “The outlook for improved carbon capture technology,” *Progress in Energy and Combustion Science*, 2012. vol. 38, no. 5, pp. 630-671.

[31] M. Mukherjee, S. Mondal, and A. Chowdhury, “Ambit of carbon capture technology in India,” *International Letters of Chemistry, Physics and Astronomy*, 2015, vol. 59, pp. 46-52.

[32] O. D. Q. F. Araujo and J. L. de Medeiros, “Carbon capture and storage technologies: present scenario and drivers of innovation,” *Current Opinion in Chemical Engineering*, 2017, vol. 17, pp. 22-34.

[33] Abdul-Aziz, A.L.O.A.A.R., Building maintenance Processes, Principles, Procedures, Practices and Strategies. 2015: p. 129.

[34] G. Clark, P. Mehta, and T. Thomson, “Application of knowledge-based systems to optimised building maintenance management,” in Industrial and Engineering Applications of Artificial Intelligence and Expert Systems. 5th International Conference, IEA/AIE-92, 9-12 June 1992. 1992. Berlin, Germany: Springer-Verlag.

[35] B. B. Sabir, S. Wild, and J. Bai, “Metakaolin and calcined clays as pozzolans for concrete: A review,” *Cement and Concrete* Composites, 2001. vol. 23, no. 6, pp. 441-454.

[36] S. Tsimas and M. Zervaki, “Reuse of waste water from ready-mixed concrete plants,” *Management of Environmental Quality: An International Journal*, vol. 22, no. 1, pp. 7-17, 2011.

[37] J. M. Khatib, “Metakaolin concrete at a low water to binder ratio,” Construction *and Building Materials*, vol. 22, no. 8, pp. 1691-1700, 2008.

[38] V. Ponmalar and R. A. Abraham, “Study on effect of natural and ground rice-husk ash concrete,” *KSCE Journal of Civil* Engineering, vol. 19, no. 6, pp. 1560-5, 2015.

[39] C. Pade and M. Guimaraes, "The CO2 uptake of concrete in a 100 year perspective," *Cement and Concrete Research*, vol. 37, no. 9, pp. 1348-1356, 2007.

[40] L. M. Bjerge, (2010). Production of cement – Environmental Challanges. COIN workshop on Concrete Ideas for Passive Houses.

[41] J. Pinto, B. Vieira, et al. "Corn cob lightweight concrete for non-structural applications," *Construction and Building Materials*, vol. 34, no. 0, pp. 346-351, 2012.

[42] A. Trümer and H. M. Ludwig, "Assessment of calcined clays according to the main criterions of concrete durability," Dordrecht, 2018, pp. 475-481: Springer Netherlands.

[43] M. Schneider, M. Romer, M. Tschudin, and H. Bolio, "Sustainable cement production—present and future," *Cement and Concrete Research*, vol. 41, no. 7, pp. 642-650, 2011/07/01/ 2011.

[44] Q. Ma and M. Bai, "Mechanical behavior, energy-storing properties and thermal reliability of phase-changing energy-storing concrete," *Construction and Building Materials*, vol. 176, pp. 43-49, 2018/07/10/ 2018.

[45] M. Hajmohammadian Baghban, P.J. hovde, A. Gustavsen, Numerical Simulation of a Building Envelope with High

Performance Materials, in: COMSOL Conference, Paris, France, 2010
[46] E. Özrahat and S. Ünalan, "Thermal performance of a concrete column as a sensible thermal energy storage medium and a heater," *Renewable Energy*, vol. 111, pp. 561-579, 2017/10/01/ 2017.
[47] M. Hajmohammadian Baghban, P.J. Hovde, S. Jacobsen, Analytical and experimental study on thermal conductivity of hardened cement pastes, Materials and Structures , 46 (9) DOI 10.1617/s11527-012-9995-y
[48] R. Wang, M. Ren, X. Gao, and L. Qin, "Preparation and properties of fatty acids based thermal energy storage aggregate concrete," *Construction and Building Materials*, vol. 165, pp. 1-10, 2018/03/20/ 2018.
[49] Y. F. Su, R. R. Kotian, and N. Lu, "Energy harvesting potential of bendable concrete using polymer based piezoelectric generator," *Composites Part B: Engineering*, vol. 153, pp. 124-129, 2018/11/15/ 2018.