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SUSTAINABLE CONCRETE WITH SILICA: OVERVIEW ON CO2 EMISSION AND GREENHOUSE GASES

Maria Ajmal[1*], Shaukat Ali[1], Asif Hanif Chaudhry[3], Nosheen Sial[4], Muhammad Aslam[5]
[1*]Department of Chemistry, superior University, Lahore
[2]Building Research Station, Lahore. Communication and Works Department, Government of Punjab.
[3]Geological Survey of Pakistan, Lahore
[4]Government Graduate College for Women, Gulberg, Lahore
[5]Department of Chemistry, University of Education, Lahore

Article Info
*Corresponding Author
mariarana.ctn@gmail.com

Abstract

Silica nanoparticles are used as admixture during the concrete formation, will increase the mechanical and durability properties. When Silica added to concrete as a mineral addition, silica fume will replace part of the cement then the use of cement for concrete formation will be reduced and in turns reduce CO2 emissions. A possible strategy to lower CO2 emissions and lessen the environmental effect of concrete manufacturing is to use silica in sustainable concrete. Silica, which comes from industrial by-products like fly ash and slag, may be added to concrete mixes to improve durability and performance and reduce CO2 emissions significantly. The construction sector may support environmentally friendly building solutions and contribute to initiatives to reduce greenhouse gas emissions by implementing sustainable concrete techniques. The performance of nanoscale Silica in cement paste has been reviewed in this work. In the presence of nano silica (SiO2), the compressive strength of cured cement paste improved along with the development of Calcium Silicate Hydrate (C-S-H) crystals. With the addition of nanosilica, the heat of hydration gradually rose which also served as a cleaning agent

Keywords

Sustainable development; Greenhouse gases; Environment; Concrete; Kyoto protocol.

1. Introduction

The most used building material in the world, concrete is prized for its strength, adaptability, and durability. Conventional concrete manufacturing, however, uses a lot of energy and emits a lot of CO2, which deteriorates the environment and accelerates climate change. The need for sustainable concrete buildings is to minimize environmental effect .The purpose of this study is to give an overview of environment friendly methods for building with concrete that reduce greenhouse gas emissions and CO2 emissions. One of the main sources of CO2 emissions in the production process is cement, an essential component of concrete. The main ingredient in cement, limestone, is calcined, which produces CO2 as a byproduct and accounts for around 8% of world CO2 emissions (Shan, Fang *et al*. 2021). Methane (CH4) and nitrous oxide (N2O), two other greenhouse gases produced during the making of concrete in addition to CO2, are emitted during the process and contribute to global warming.(Kaptan, Cunha *et al*. 2024) An important component of traditional concrete mixes is frequently Portland cement, which emits a lot of greenhouse gases(Hafez, Kurda *et al*. 2019) . Portland cement may be largely replaced in concrete mixes by alternative cementitious materials such fly ash, slag, and silica fume, which will lower CO2 emissions and increase sustainability(Shan, Fang *et al*. 2021). Low-embodied carbon emissions low-carbon binders, such geopolymers and calcium sulfoaluminate cements, provide an alternative to conventional Portland cement (Bernal, Verde *et al*. 2016). Reusing and recycling concrete debris from building and demolition projects can lessen the impact of concrete production on the environment and the need for virgin materials (Tam 2008). In the process of making concrete, using renewable energy sources like solar or wind power helps lessen the manufacturing carbon impact and encourage sustainable behaviors. A thorough process called life cycle assessment is used to examine how concrete structures affect the environment at every stage of their existence, from the extraction of raw materials to the disposal of the structure at the end of its useful life. In order to evaluate the overall sustainability of concrete structures, LCA takes into account a number of environmental effect categories (Cuce, Sher *et al*. 2019). Sustainable concrete technologies have advanced, obstacles like cost competitiveness, performance constraints, and scalability prevent widespread implementation in the building sector (Guinée 2002). Economic variables are critical in propelling the adoption of sustainable concrete solutions and fostering market transformation. These elements include market demand, pricing strategies, and regulatory incentives (Pomponi and Moncaster 2017). Numerous building and construction materials, particularly wood-based surface materials, have been found to potentially emit hydrocarbons into indoor air.(Marć, Zabiegała *et al*. 2012) (Yrieix, Dulaurent *et al*. 2010, Yu and Kim 2010, Liang and Xu 2014, Curran and Strlič 2015, Harb, Locoge *et al*. 2018). A large variety of building materials are employed in construction. Certain materials such wood, plastics, paints, adhesives and biomaterials have the potential to release CO2 emission. (Nohr, Horn *et al*. 2015, Horn, Richter *et al*. 2018). In an effort to promote sustainable concrete and lower carbon emissions, geopolymer, a ceramic material with cement-like qualities was created and marketed as a cement substitute. Materials rich in silica and aluminate, such as fly ash, metakaolin, etc., are combined with an alkaline solution to create geopolymer mixture in the necessary ratio. (Aliabdo, Abd Elmoaty *et al*. 2016, Ji, Zhang *et al*. 2023) Sodium silicate, potassium hydroxide, potassium silicate, and calcium hydroxide are the alkalis utilized in the alkali activation process. These alkalis dissolve the fly ash and create an inorganic substance with an alumina-silicate basis. This substance functions as a binding agent by forming Si-O-Al-O bonds and 3D polymeric chains (Temuujin, van Riessen *et al*. 2010). We have concentrated our analysis on greenhouse gas emissions, which are expressed in CO2 equivalent units. These pollutants are worldwide in nature (Epa 2010). Thermal infrared radiation released by the Earth's surface and atmosphere is absorbed by infrared active gases, which are mostly water vapor, carbon dioxide, and ozone that are naturally present in the atmosphere. Due to this the atmosphere becomes warmed and releases infrared radiation most of which acts to warm the surface and lower atmosphere. As a result, Earth's average surface air temperature is higher than it will be in the absence of atmospheric infrared radiation absorption(Ledley, Sundquist *et al*. 1999) Greenhouse effect and the infrared active gases that cause it are also known as greenhouse gases. From the start of the industrial era greenhouse gas concentrations have increased, raising concerns about possible climatic impacts (German, Wang *et al*. 1992).Out of all the man-made greenhouse gases, carbon dioxide is the primary contributor to future global warming due to its significant greenhouse forcing both now and in the future (Houghton 1996).Some sources of greenhouse gases are depicted in Figure1.

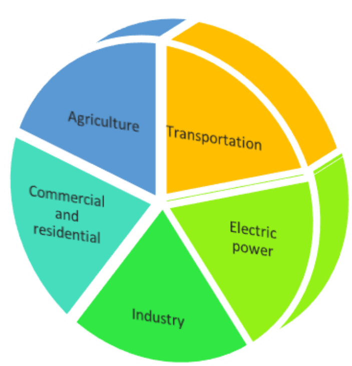

Figure 1: Sources of Greenhouse emission

The number of sectors producing greenhouse gases that have an impact on people has increased recently. CO_2, methane gas, NO_2, and other gases are the most dangerous of all. (Kattenberg, Giorgi *et al*. 1996, Krabill, Frederick *et al*. 1999, Dyurgerov and Meier 2005).This system uses matchings sensors interfaced with a wireless sensor network that monitor greenhouse gas leaks from industries, including CO_2, NO_2, humidity, and temperature(Krabill, Frederick *et al*. 1999). Heat emitted from the Earth's surface is trapped by these gasses. This effect is brought about by the bonds that exist between the molecules of greenhouse gases. The Earth's surface can be made warmer overall with sufficient greenhouse gas emissions.(Herzog, Eliasson *et al*. 2000). The greenhouse effect, strong storms in coastal regions, disruptions to agricultural and drinking water supplies, changes in biodiversity, plant distribution changes, and changes in soil moisture all contribute to the rise in sea levels caused by global warming. It has brought about more droughts, heavier rains, floods, and forest fires, all of which pose a serious danger to the habitat of all life on Earth.(Latake, Pawar *et al*. 2015). A new idea that has been put out to direct economic development planning is sustainable development. Both wealthy and developing nations can use it. (James, Nijkamp *et al*. 1989).It makes the case that managing the environment, which involves a variety of tasks like preventing and controlling pollution of the air, water, and noise; maintaining ecological balance and conserving nonrenewable resources; and making appropriate and cautious use of renewable resources(Muttagi 1998).The word sustainable describes how the global economy is managed to ensure that the planet's seas, atmosphere, climate, and ecosystems continue to operate healthily. (Baker and Mehmood 2015, Halvorsen, Koutsopoulos *et al*. 2020). International agreements that take account of the principle that the emission reductions should be secured at minimum cost.(Martin, Burniaux *et al*. 1992).Typology of sustainable development is describes in Figure 2.

Figure 2: Typology of sustainable development

The energy and carbon footprint in relation to international environmental treaties and the mitigation of climate change initiatives undertaken by 11 major polluting nations.(Oikonomou, Polemis *et al*. 2021). Over 160 parties contribute to the United Nations Framework Convention on Climate

Change on the Kyoto Protocol in Kyoto, Japan, in December 1997(Cooper 2001).This protocol sets legally binding emissions limits for industrialized nations on carbon dioxide and other greenhouse gases for the first time.(Malin 1998). It is said that the Kyoto Protocol is seen as a modest success despite the many issues that exist(Zawrah, El-Kheshen *et al*. 2009). Some important Kyoto protocol factors are given in Figure 3.

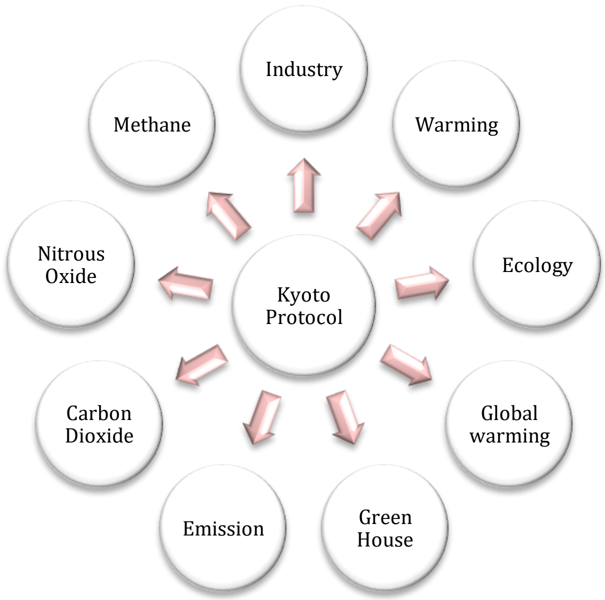

Figure 3: Kyoto Protocol

The Protocol implies to create backup plans for sequestering carbon gasses and adapting to climate change.(Wang, Martin *et al*. 2012). A beginning has been made by governments to address climate changes(Snyder, Lee *et al*. 2007). Investigations were conducted into the economical preparation and characterization of silica nanoparticles for a sustainable environment friendly that will reasonably price the best synthesis conditions for silica nanoparticle formation were discovered through a series of experiments, and the resulting silica nanoparticles were examined using a transmission electron microscope, X-ray diffraction, infrared spectra, and thermogravimetric analysis.(Srivastava, Agarwal *et al*. 2013).Rice husks is used to create biogenic silica nanoparticles. The silica nanoparticles are found to be made up of smaller primary particles, and the clustering of these particles produced a porous structure, according to the characterizations. Such clusters of silica nanoparticles eventually fuse to produce semicrystalline porous silica frameworks with controllable pore size and structural integrity under the controlled melting catalyzed.(Panjehpour, Ali *et al*. 2011). By using a unique dip-coating apparatus, silica nanoparticles easily ordered into multilayer and monolayer coatings across.(Temiz and Karakeci 2002). Many characteristics of cement, including as workability, durability, strength, resistance to fractures, and permeability, can be enhanced by the inclusion of certain pozzolanic elements. Among these pozzolanic materials is silica fume. Concrete may have its stickiness increased by adding silica fume. Concrete's compressive, tensile, flexural, and impact strengths are increased when silica fume is added, but permeability and bleeding are reduced.(Torkan, Hejazi *et al.* 2023). Portland cement included mineral additives, sometimes referred to as mineral admixtures. These days, there are two kinds of additives that are frequently combined with cement or mixed with Portland clinker. Silica fume is a highly refined, separated silica that is produced as an industrial byproduct. It is added to the concrete mixture as an additive, and the qualities of the finished product are greatly impacted by it. (Flores-Vivian, Pradoto *et al.* 2017). Mineral admixtures are made with silica fume. X-ray diffraction and scanning electron microscopy are used to examine the impact of various admixtures on the microstructure of cement paste. Portland cement contains portlandite, which reacts with SF to generate a new calcium-silicate-hydrate gel (Yazdanbakhsh and Grasley 2014). In order to enhance cementitious materials performance in particular applications such as high strength and durability in concretes NS is being added to them (Papatzani 2016) .SiO_2 nanoparticles are added to cement systems in order to change the rheological behavior, increase the reactivity of additional cementitious ingredients, and boost durability and strength. Low-cost nano-SiO_2 particles derived from naturally occurring hydrothermal solutions using membrane ultrafiltration and, if desired, cry chemical vacuum sublimation drying in systems based on Portland cement. X-Ray Diffraction, Scanning Electron Microscope (SEM), and Fourier Transform Infrared (FTIR) spectroscopy methods were used to analyze the nanoparticles. Some cement admixtures are given below in Figure 4.

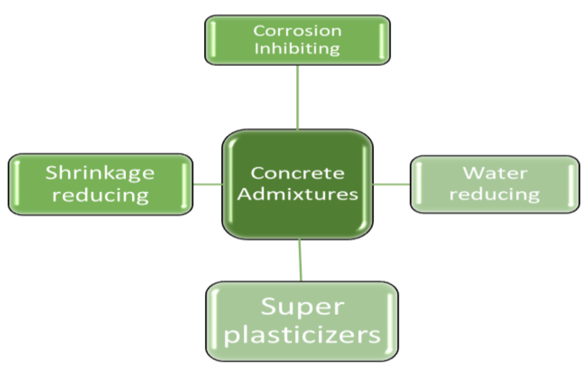

Figure 4: Concrete Admixtures

Using nano-SiO_2 particles enhance strength characteristics and lessen segregation (Rogalski, Bęś *et al.* 2008). Optical microscopy is used to view specimens integrated cement paste with varying amounts of silica fume in order to assess the methods efficacy. The findings indicate that the deagglomeration in fresh cement paste may be substantially inhibited by the application of silica fume in adequate amounts.(Golovatskaya and Dyukarev 2012). Nanotechnology research is gained momentum due to the necessity to manufacture sustainable cements. Since calcium silicate hydrate is the primary result of cement hydration, adding nanoparticles to blended Portland cement compositions can significantly alter their mechanical strength, porosity, and durability(Anwar, Iftikhar *et al*. 2019). Carbon dioxide is a substance found in atmospheric air and is continually exchanged between ecosystems and the environment. It also shows the pace at which organic matter breaks down during industrial waste management and the restoration of degraded land, as well as the rate at which processes occur in the soil environment. The concentration of CO_2 in the atmosphere rise as a result of human activities increasing CO_2 emissions into the atmosphere. Numerous variables, including as temperature, humidity, porosity, root respiration, etc., affect the CO_2 level of soil air. CO_2 emission is measured in a controlled environment chamber with a constant water capacity (Kristensen, Flindt *et al*. 2008). It was demonstrated that the air temperature and the peat deposit's surface have a reliable impact on the emission of CO_2 on all time scales(Papatzani and Paine 2018).Rapid increases in human activity increase carbon dioxide (CO_2) emissions and created urgent global environmental problems. Global warming, which results in global climate change, is mostly cause by CO_2. The concentration of CO_2 in the atmosphere has grown. The rate of increase in CO_2 emissions is the melting of glaciers, heat waves, droughts, cyclones, storms, and problems with food security. The majority of global contributions come from nations like China, the United States, India, Russia, Japan, Korea, Germany, Iran, Canada, the United Kingdom, and others (Sarade, Namdev *et al*. 2017).

2. Reduction in emission of CO_2 by using Silica Nano particles

Now we will discuss how to reduce this emission of CO_2 by using silica nanoparticles as cement admixtures. Our understanding of science, the world, and subsequently the built environment has all been altered by nanotechnology. Sustainability in cement is crucial, and nanotechnology provide new ways to reduce CO_2 emissions by increasing the percentage of byproducts, decreasing clinker, and developing more lasting formulations. Analyses using thermal gravimetric and X-ray diffraction indicated that Ca (OH)2 is consumed in the process of producing C-S-H(Reches 2018). Constraints are established by a thorough analysis of the addition of nano silica particles at four distinct doses for increases in strength, hydration, and microstructural properties, it is discovered that nano silica and inorganic nano material particles worked best at lower doses(Pacheco-Torgal and Jalali 2011). There is a global concern about CO_2 emissions, and the cement sector contributes around 8% of the CO_2 emissions worldwide through the clinkering process. The declination of limestone, the fuel used in the clinkering process, and the power used are the main causes of the CO_2 footprint. Therefore, in an effort to lessen the carbon footprint, cement experts are concentrating on substituting different supplemental cementitious materials for Portland cement. It is generally known that cement make the microstructures of concrete denser. Cement is one of the binder ingredients used in concrete, which is the most widely used material in building. Nano silica powder may partially replace cement. Subsequently, replacement will be performed in order to compare the compressive strength of concrete with and without nano silica addition. By lowering the amount of CO_2 emitted into the atmosphere, nano silica can effectively minimize pollution in the environment. Through this concrete's permeability will improve.(Huseien 2023).

3. The basic equation for the estimation of CO_2 emission is following

CO_2 Emission: Cement Production **X** CO_2 Emission Factor

Whereas cement production is the total amount of cement produced and emission factor is the amount of CO_2 emitted per metric ton For example, we are using 100 tons of cement and its emission factor is 0.9 tons of CO_2 Per ton of cement. Then the CO_2 emission will CO_2 Emission= 100 tons **X** 0.9 tons of CO_2 per ton of cement CO_2 Emission= 90 tons of CO_2 . The CO_2 emissions for each batch of cement containing silica nanoparticles will be computed with the assumption that the silica nanoparticles will lower CO_2 emissions by 10%. The emission factor (0.9 metric tons of CO_2 per metric ton of cement produced) that was previously specified will be used.

Table 1: Difference between CO2 emission with and without silica nano particles

Quantity of Cement (Tons)	CO_2 Emissions without Silica Nanoparticles (tons)	CO_2 Emissions with Silica Nanoparticles (tons)
100	90	81
70	63	56.7
50	45	40.5
30	27	24.3
10	09	8.1

Portland cement is the main binding material used in the building sector because of its quick expansion and development. The primary environmental concern associated with the manufacturing of regular Portland cement is the release of carbon dioxide into the atmosphere, which results from burning fossil fuels and the calcination of limestone. A decrease in the use of Portland cement will result in a decrease in the demand for the material, which will lower carbon dioxide emissions(Shaik, Adil *et al*. 2023). In the construction industry, nanotechnology has undoubtedly been a major invention that has advanced the development of long-lasting, high-performance building materials(Alhassan, Alkhawaldeh *et al*. 2023) . The remarkable scientific advancements in the field of nanotechnology have made it possible to effectively use a variety of nanoscale materials with unique properties, enhancing the fundamental qualities of conventional building materials like concrete.

(Dugay, Evers *et al*. 2018, Parashar, Shukla *et al*. 2020). Major advancements in nanotechnology and nanomaterials have made it possible to incorporate different qualities of the materials that have been developed to solve concrete's durability problems, with the potential advantage of significantly reducing service and maintenance costs for the future construction industry (Ahmed, Sharma *et al*. 2009). Due to the quick advancement of synthesis and characterization methods in nanomaterial technology, scientists are now able to plan a variety of applications for conductive ultra-small nanoparticles of various metal oxides, carbon, and metals(El-Safty 2008, Ghosh Chaudhuri and Paria 2012). NPs with a variety of sizes, forms, and geometries may now be created, such as spheres, prisms, hexagons, cubes, wires, tubes, fibers, clay, needles, rods, and so on.(Bhatia and Bhatia 2016, Jones, Gibb *et al*. 2019). It shows the NP classification system based on the several sorts of sources, including carbon-based, inorganic, and organic (Lin and Chen 2017). Based on their composition, these Nano particles broadly divided into two groups: those based on organic carbon and those based on inorganic compounds(Norhasri, Hamidah *et al*. 2017). Utilizing paints can result in enhanced antibacterial capabilities (Vikulin, Alekseev *et al*. 2011). The characteristics of many materials have been altered fundamentally by the application of advanced nanotechnology. Nano clay may be extensively used in the building industry at a notably reduced cost, promoting economy and sustainability in the industry(Said, Zeidan *et al*. 2012). It has been demonstrated that adding NPs to concrete improves both its overall performance and characteristics. It is possible to significantly increase general bulk characteristics and early mechanical strength. It examines the application of different industrial nanomaterials as additives to improve cementitious material and its microstructures, resulting in long-term improvements in the world's building industries.

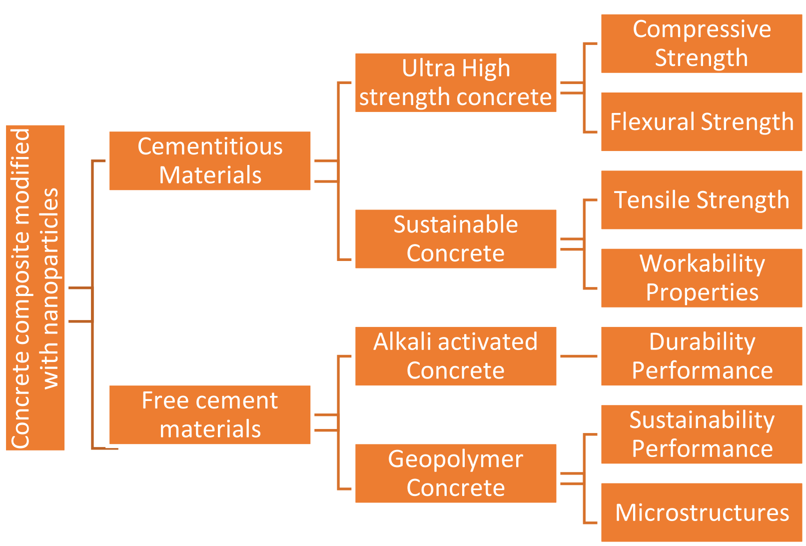

Figure 5: Review of various NP modified concrete

Nanoparticles may increase the mechanical strength of the products(Huseien, Shah *et al*. 2019). Main impacts of nanoparticles are often seen in modified concretes and mortars.

1) They serve as pore fillers in the concrete matrix, making mortars more compact.
2) The strong electrostatic force of these nano particles promotes hydration in the cement mixture and generates new nucleation sites that in turn produce more C-S-H gel clusters.
3) The nano particles perform the roles of microcrack and pore filling, which improve homogeneity and make the network more compact than traditional cement-based concretes.
4) Nano particles high reactivity with Ca (OH)2 suggests a robust chemical reaction and increased consumption, necessitating the use of additional water.
5) They gather the micropores, which initiates a process of microcrack refinement early on and improves the microstructures of concrete matrices. Exposure to chloride, which results in the corrosion of embedded steel, continues to be a significant issue for the extended use of concrete structures.
6) The quick corrosion of the steel reinforcement resulting from the spread of chloride ions in the concrete leads to many cracks in the reinforced steel and ultimately the breaking of the concrete.
7) The transport mechanism of chloride ions is a multifaceted system that may involve capillary absorption, water diffusion, and impregnation. Solutions to this problem have thus attracted a lot of scientific attention. The inclusion of nano particles in concretes may significantly reduce the penetration of chloride ions, shielding the steel structure from oxidation.

The durability can be increased and the depth of chloride penetration may be decreased by adding nano silica to the cement matrix.(Hamzah, Joudah *et al*. 2021). The advantages of using nanomaterials in concrete is for long-term environmental sustainability (Shah and Huseien 2020). The 21st century is all about sustainable development, and concretes based on nanomaterials can help create new environmentally friendly construction goods and provide us a better knowledge of how nanomaterials interact with the environment. Fundamentally, because of their strength, durability, and sustainability, nanoparticles used in building have the potential to be beneficial.

4. Advantages of using Nano silica

The following findings might be reached thanks to this comprehensive analysis of nano-based concrete composites:

- Concrete setting periods is shortened when nano particles are added and the hydration rate is significantly increased.
- Mixes made using nanoparticles exhibit a remarkable increase in strength performance. The formation of thick gels and dense surface morphology can be significantly impacted by the inclusion of nano particles in cement binders.

- By incorporating the nano particles into the concrete matrix, the durability and porosity and penetration of nano particle modified concrete composites can be improved.
- Compared to other nanomaterials, the addition of OPC composite can enhance its engineering qualities more.
- It was discovered that adding nano silica to a cement-free binder accelerated the polymerization processes, shortened the setting period, and improved the mechanical and durable qualities of the resulting geopolymer binders.
- Because of the difficulties of development of weak patches within the binder matrix, an increase in the nano particle content over the optimal might have a deep impact on the mechanical and durability properties of concrete.
- Using different possible nanomaterials carefully as additives can be a creative way to improve cementitious materials' microstructures, which might eventually result in sustainable improvements in the global building industry.
- When silica added to concrete as a mineral addition or supplemental material, silica fume can significantly lower CO_2 emissions linked to the manufacturing of cement, a major cause of global warming.
- The finished product has better mechanical and physical qualities when silica fume is added to concrete mixes, which increases durability.

Conclusion

The overall carbon dioxide emissions related to the manufacturing of concrete greatly decreased by substituting a part of the cement with silica, which consumes less energy and produces less greenhouse gases throughout the process. Comparing sustainable concrete with silica admixtures to conventional concrete mixes, the former frequently showed better strength, durability, and workability. This resulted in, longer-lasting structures, which would further improve the sustainability of building projects. Overall energy efficiency influenced by the reduced energy needed for silica processing and the possibility of improved thermal performance of concrete containing silica. It has been discovered that some silica forms, including rice husk ash, have pozzolanic qualities, which enable them to react with the calcium hydroxide created during cement hydration. To sum up, silica-infused sustainable concrete presents a workable solution to cut CO2 emissions and lessen the negative environmental effects of concrete manufacturing as described in Table: 1 that CO_2 emission is reduced by 10 percent. Through the utilization of novel materials and industrial by-products, the building sector may shift to more ecologically sustainable methods without sacrificing structural integrity or performance.

References

Ahmed, J., S. Sharma, K. V. Ramanujachary, S. E. Lofland and A. K. Ganguli (2009). "Microemulsion-mediated synthesis of cobalt (pure fcc and hexagonal phases) and cobalt–nickel alloy nanoparticles." *Journal of colloid and interface science* 336(2): 814-819.

Alhassan, M., A. Alkhawaldeh, N. Betoush, M. Alkhawaldeh, G. F. Huseien, L. Amaireh and A. Elrefae (2023). "Life cycle assessment of the sustainability of alkali-activated binders." Biomimetics 8(1): 58.

Aliabdo, A. A., M. Abd Elmoaty and H. A. Salem (2016). "Effect of cement addition, solution resting time and curing characteristics on fly ash based geopolymer concrete performance." Construction and building materials 123: 581-593.

Anwar, M., M. Iftikhar, B. Khush Bakhat, N. Sohail, M. Baqar, A. Yasir and A. Nizami (2019). "Sources of carbon dioxide and environmental Issues." Sustainable Agriculture Reviews 37: Carbon Sequestration Vol. 1 Introduction and Biochemical Methods: 13-36.

Baker, S. and A. Mehmood (2015). "Social innovation and the governance of sustainable places." Local Environment 20(3): 321-334.

Bernal, J. L., L. Verde and A. G. Riess (2016). "The trouble with H0." *Journal of Cosmology and Astroparticle Physics* 2016(10): 019.

Bhatia, S. and S. Bhatia (2016). "Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications." Natural polymer drug delivery systems: Nanoparticles, plants, and algae: 33-93.

Cooper, R. N. (2001). The Kyoto Protocol: a flawed concept. workshop on" Trade and the Environment in the Perspective of the EU Enlargement" by Fondazione Eni Enrico Mattei (FEEM), Milano (Italy).

Cuce, E., F. Sher, H. Sadiq, P. M. Cuce, T. Guclu and A. B. Besir (2019). "Sustainable ventilation strategies in buildings: CFD research." Sustainable Energy Technologies and Assessments 36: 100540.

Curran, K. and M. Strlič (2015). "Polymers and volatiles: Using VOC analysis for the conservation of plastic and rubber objects." Studies in Conservation 60(1): 1-14.

Dugay, J., W. Evers, R. Torres-Cavanillas, M. Giménez-Marqués, E. Coronado and H. S. Van der Zant (2018). "Charge mobility and dynamics in spin-crossover nanoparticles studied by time-resolved microwave conductivity." *The journal of physical chemistry letters* 9(19): 5672-5678.

Dyurgerov, M. B. and M. F. Meier (2005). Glaciers and the changing Earth system: a 2004 snapshot, Institute of Arctic and Alpine Research, University of Colorado Boulder.

El-Safty, S. A. (2008). "Synthesis, characterization and catalytic activity of highly ordered hexagonal and cubic composite monoliths." *Journal of colloid and interface science* 319(2): 477-488.

Epa, U. (2010). "Motor vehicle emission simulator (moves) user guide." US Environmental Protection Agency.

Flores-Vivian, I., R. G. Pradoto, M. Moini, M. Kozhukhova, V. Potapov and K. Sobolev (2017). "The effect of SiO 2 nanoparticles derived from hydrothermal solutions on the performance of portland cement based materials." Frontiers of Structural and Civil Engineering 11: 436-445.

German, M. S., J. Wang, R. B. Chadwick and W. J. Rutter (1992). "Synergistic activation of the insulin gene by a LIM-homeo domain protein and a basic helix-loop-helix protein: building a functional insulin minienhancer complex." Genes & development 6(11): 2165-2176.

Ghosh Chaudhuri, R. and S. Paria (2012). "Core/shell nanoparticles: classes, properties, synthesis mechanisms, characterization, and applications." Chemical reviews 112(4): 2373-2433.

Golovatskaya, E. and E. Dyukarev (2012). "The influence of environmental factors on the CO 2 emission from the surface of oligotrophic peat soils in West Siberia." Eurasian Soil Science 45: 588-597.

Guinée, J. B. (2002). Handbook on life cycle assessment: operational guide to the ISO standards, Springer Science & Business Media.

Hafez, H., R. Kurda, W. M. Cheung and B. Nagaratnam (2019). "A systematic review of the discrepancies in life cycle assessments of green concrete." Applied Sciences 9(22): 4803.

Halvorsen, A., H. N. Koutsopoulos, Z. Ma and J. Zhao (2020). "Demand management of congested public transport systems: a conceptual framework and application using smart card data." Transportation 47(5): 2337-2365.

Hamzah, H. K., Z. H. Joudah, D. P. Georgescu, N. H. A. Khalid and G. F. Huseien (2021). "Laboratory evaluation of alkali-activated mortars modified with nanosilica from glass bottle wastes." Materials Today: Proceedings 46: 2098-2104.

Harb, P., N. Locoge and F. Thevenet (2018). "Emissions and treatment of VOCs emitted from wood-based construction materials: Impact on indoor air quality." *Chemical Engineering Journal* 354: 641-652.

Herzog, H., B. Eliasson and O. Kaarstad (2000). "Capturing greenhouse gases." Scientific American 282(2): 72-79.

Horn, W., M. Richter, M. Nohr, O. Wilke and O. Jann (2018). "Application of a novel reference material in an international round robin test on material emissions testing." Indoor air 28(1): 181-187.

Houghton, J. T. (1996). Climate change 1995: The science of climate change: contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Huseien, G. F. (2023). "A review on concrete composites modified with nanoparticles." *Journal of Composites Science* **7**(2): 67.

Huseien, G. F., K. W. Shah and A. R. M. Sam (2019). "Sustainability of nanomaterials based self-healing concrete: An all-inclusive insight." *Journal of Building Engineering* 23: 155-171.

James, D. E., P. Nijkamp and J. B. Opschoor (1989). Ecological sustainability and economic development. Economy and ecology: Towards sustainable development, Springer: 27-48.

Ji, Z., G. Zhang, Y. Chen, R. Liu, J. Qu and H. Liu (2023). "Synchronous recycling of multisource solid wastes for low-carbon geopolymer preparation: Primary factors identification and feasibility assessment." *Journal of Cleaner Production* 430: 139633.

Jones, W., A. Gibb, C. Goodier, P. Bust, M. Song and J. Jin (2019). "Nanomaterials in construction–what is being used, and where?" Proceedings of the institution of civil engineers-construction materials 172(2): 49-62.

Kaptan, K., S. Cunha and J. Aguiar (2024). "A Review: Construction and Demolition Waste as a Novel Source for CO2 Reduction in Portland Cement Production for Concrete." Sustainability 16(2): 585.

Kattenberg, A., F. Giorgi, H. Grassl, G. Meehl, J. Mitchell, R. Stouffer, T. Tokioka, A. Weaver and T. Wigley (1996). Climate models: projections of future climate. Climate Change 1995: the science of climate change. Contribution of WG1 to the Second Assessment Report of the IPCC, Cambridge University Press: 299-357.

Krabill, W., E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright and J. Yungel (1999). "Rapid thinning of parts of the southern Greenland ice sheet." Science 283(5407): 1522-1524.

Kristensen, E., M. R. Flindt, S. Ulomi, A. V. Borges, G. Abril and S. Bouillon (2008). "Emission of CO2 and CH4 to the atmosphere by sediments and open waters in two Tanzanian mangrove forests." Marine Ecology Progress Series 370: 53-67.

Latake, P. T., P. Pawar and A. C. Ranveer (2015). "The greenhouse effect and its impacts on environment." Int. J. Innov. Res. Creat. Technol 1(3): 333-337.

Ledley, T. S., E. T. Sundquist, S. E. Schwartz, D. K. Hall, J. D. Fellows and T. L. Killeen (1999). "Climate change and greenhouse gases." Eos, Transactions American Geophysical Union 80(39): 453-458.

Liang, Y. and Y. Xu (2014). "Improved method for measuring and characterizing phthalate emissions from building materials and its application to exposure assessment." Environmental science & technology 48(8): 4475-4484.

Lin, C.-C. and W.-Y. Chen (2017). "Effect of paint composition, nano-metal types and substrate on the improvement of biological resistance on paint finished building material." Building and Environment 117: 49-59.

Malin, C. B. (1998). "The Kyoto protocol: A business perspective." *Oil and Gas Journal* 96(3).

Marć, M., B. Zabiegała and J. Namieśnik (2012). "Testing and sampling devices for monitoring volatile and semi-volatile organic compounds in indoor air." TrAC Trends in Analytical Chemistry 32: 76-86.

Martin, J. P., J.-M. Burniaux, G. Nicoletti and J. Oliveira-Martins (1992). "The Costs of International Agreements to Reduce CO~ 2 Emissions: Evidence from Green." OECD Economic Studies: 93-93.

Muttagi, P. K. (1998). "SUSTAINABLE DEVELOPMENT--A THIRD WORLD PERSPECTIVE." Sustainable development and the future of cities.

Nohr, M., W. Horn, O. Jann, M. Richter and W. Lorenz (2015). "Development of a multi-VOC reference material for quality assurance in materials emission testing." Analytical and bioanalytical chemistry 407: 3231-3237.

Norhasri, M. M., M. Hamidah and A. M. Fadzil (2017). "Applications of using nano material in concrete: A review." Construction and Building Materials 133: 91-97.

Oikonomou, A., M. Polemis and S.-E. Soursou (2021). "International environmental agreements and CO2 emissions: fresh evidence from 11 polluting countries." *Journal of Risk and Financial Management* 14(7): 331.

Pacheco-Torgal, F. and S. Jalali (2011). "Nanotechnology: Advantages and drawbacks in the field of construction and building materials." Construction and building materials 25(2): 582-590.

Panjehpour, M., A. A. A. Ali and R. Demirboga (2011). "A review for characterization of silica fume and its effects on concrete properties." *International Journal of Sustainable Construction Engineering and Technology* 2(2).

Papatzani, S. (2016). "Effect of nanosilica and montmorillonite nanoclay particles on cement hydration and microstructure." Materials Science and Technology 32(2): 138-153.

Papatzani, S. and K. Paine (2018). "Lowering cement clinker: A thorough, performance based study on the use of nanoparticles of SiO2 or montmorillonite in Portland limestone nanocomposites." *The European Physical Journal Plus* 133(10): 430.

Parashar, M., V. K. Shukla and R. Singh (2020). "Metal oxides nanoparticles via sol–gel method: a review on synthesis, characterization and applications." *Journal of Materials Science: Materials in Electronics* 31(5): 3729-3749.

Pomponi, F. and A. Moncaster (2017). "Circular economy for the built environment: A research framework." *Journal of cleaner production* 143: 710-718.

Reches, Y. (2018). "Nanoparticles as concrete additives: Review and perspectives." Construction and Building Materials 175: 483-495.

Rogalski, L., A. Bęś and K. Warmiński (2008). "Carbon dioxide emission to the atmosphere from overburden under controlled temperature conditions." *Polish Journal of Environmental Studies* 17(3): 427-432.

Said, A. M., M. S. Zeidan, M. Bassuoni and Y. Tian (2012). "Properties of concrete incorporating nano-silica." Construction and building materials 36: 838-844.

Sarade, R., R. Namdev, M. Pawar and S. Shinde (2017). "Review paper on multifunctional use of nano silica in concrete." *International Journal of Engineering Science and Computing* 7(4): 10780-10782.

Shah, K. W. and G. F. Huseien (2020). "Biomimetic self-healing cementitious construction materials for smart buildings." Biomimetics 5(4): 47.

Shaik, M. R., S. F. Adil and M. Khan (2023). Novel Nanomaterials for Catalytic and Biological Applications, MDPI. 13: 427.

Shan, Y., S. Fang, B. Cai, Y. Zhou, D. Li, K. Feng and K. Hubacek (2021). "Chinese cities exhibit varying degrees of decoupling of economic growth and CO2 emissions between 2005 and 2015." One Earth 4(1): 124-134.

Snyder, M. A., J. A. Lee, T. M. Davis, L. Scriven and M. Tsapatsis (2007). "Silica nanoparticle crystals and ordered coatings using lys-sil and a novel coating device." Langmuir 23(20): 9924-9928.

Srivastava, V., V. Agarwal, R. K. Atul and P. Mehta (2013). "Silica fume–an admixture for high quality concrete." J. Environ. Nanotechnol 2: 53-58.

Tam, V. W. (2008). "On the effectiveness in implementing a waste-management-plan method in construction." Waste management 28(6): 1072-1080.

Temiz, H. and A. Karakeci (2002). "An investigation on microstructure of cement paste containing fly ash and silica fume." Cement and Concrete Research 32(7): 1131-1132.

Temuujin, J., A. van Riessen and K. MacKenzie (2010). "Preparation and characterisation of fly ash based geopolymer mortars." Construction and Building materials 24(10): 1906-1910.

Torkan, A., S. M. Hejazi, S. M. Abtahi and M. Shayannejad (2023). "Design and fabrication of fibrous media to facilitate autogenous smart self-healing properties in cracked-cementitious structures using polyethylene glycol (PEG) and silicon dioxide nanoparticles." Construction and Building Materials 407: 133518.

Vikulin, V., M. Alekseev and I. Shkarupa (2011). "Study of the effect of some commercially available nanopowders on the strength of concrete based on alumina cement." Refractories and Industrial Ceramics 52(4): 288-290.

Wang, W., J. C. Martin, X. Fan, A. Han, Z. Luo and L. Sun (2012). "Silica nanoparticles and frameworks from rice husk biomass." ACS applied materials & interfaces 4(2): 977-981.

Yazdanbakhsh, A. and Z. Grasley (2014). "Utilization of silica fume to stabilize the dispersion of carbon nanofilaments in cement paste." *Journal of Materials in Civil Engineering* 26(7): 06014010.

Yrieix, C., A. Dulaurent, C. Laffargue, F. Maupetit, T. Pacary and E. Uhde (2010). "Characterization of VOC and formaldehyde emissions from a wood based panel: results from an inter-laboratory comparison." Chemosphere 79(4): 414-419.

Yu, C. W. F. and J. T. Kim (2010). "Building pathology, investigation of sick buildings—VOC emissions." Indoor and Built Environment 19(1): 30-39.

Zawrah, M., A. El-Kheshen and H. M. Abd-El-Aal (2009). "Facile and economic synthesis of silica nanoparticles." *Journal of Ovonic Research* 5(5): 129-133.