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Role of Nanotechnology in Concrete a Cement Based Material: A Critical Review on Mechanical Properties and Environmental Impact

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Abstract

Nanotechnology is the use and study of matter or structure between 1 nanometer (nm) and 100 nanometers in size. It is the study to make use of matter at the molecular scale. As particle become nano-sized, the fraction of particle on the surface multiply virtual to those inside leads to "nano-effects" and alter the properties of the material to a great extent to produce material with novel and smart properties. Concrete, second highest consumed commodity on earth, with assimilate nanotechnology into material like concrete that will greatly improve its enviable chattels, such as strength, sturdiness, ductility, and cleanliness etc. Currently, the most dynamic research an area in terms of nanotechnology is it's dealing with cement and concrete is: understanding of the hydration of cement particles and the use of nano-size ingredient. Also, Cement industry is one of the noteworthy sources of carbon dioxide emissions, which accounts for 5-6% of global man-made carbon dioxide emission annually. Recuperating the material resistances and the escalating of their durability will reduce environmental pollution by reducing the carbon footprint of the building. A considerable improvement in the mechanical properties and durability of cementitious materials can be observed with assimilation of nano materials such as nano- Al_2O_3, ZnO_2, TiO_2, SiO_2, Carbon nanotubes, etc. Hence if the performance of the basic civil engineering raw materials is enhanced anyhow, the productivity will get increased as to work with those modified materials and the performance of the final civil engineering product will also be improved in the benefit of mankind.

Keywords

Nanotechnology, Concrete, Environmental Pollution, Nanomaterials

1. Introduction

Nanotechnology word comes from the Greek word "nanos" which indicate a billionth (1). Nanotechnology means science which deals with nanoscale to understand, control and restructuring of matter to create materials with new properties and functions (2). Nanotechnology is widely regarded as one of the twenty-first century's key technologies, and its economic weightage is speedily on the rise (3). Nanotechnology is the science of engineering that deals with particle which are less than 100 nm in size (4). One of the most active research areas that encompass a number of disciplines including civil engineering and construction materials in today's world is Nanotechnology (5). As the particle become nano sized the proportion of atoms on the surface increases relative to those inside and this leads to novel property of materials (6).

The major development in the Nanoscience of cementitious materials with an enhance in the knowledge and insight of crucial happening in cement at the nanoscale e.g. mechanical and structural properties of the core hydrate phases, cement cohesion, boundary condition in concrete, and course of action for degradation (7). Nanotechnology has been related to developments in the fields of materials sciences, microelectronics, and medicine etc. (8). However, the potential for application of many of the developments in the nanotechnology field in the area of construction engineering is

growing (9). And the significance of nanotechnology for the construction industry is becoming the future of the construction industry. Nanotechnology shows the global level trends and importance of by implementation of well known construction. The Adverse side with an application of Nanotechnology are involvement of some serious health risks (10), which should be known and care should be taken so that nano products give the full lead to human being and could be promoted in the commercial market (11).

2. Concrete

Concrete is the most widely used material on the surface of the earth after water. Concrete is used in almost all construction activities like – building, roads, dams, bridges, canal etc. (12). Without the use of concrete one cannot image the construction sector and infrastructure development in the field of civil engineering (3). Concrete is a highly assorted material prepared by the combination of finely powdered cement, aggregates of various sizes and water with inherent physical, chemical and mechanical properties (13). Concrete is the second highest consumed commodity after water used as construction material with the current population growth, economic development, and need for repair/replacement of aging infrastructure (14). In concrete a reaction between the cement and water known as the hydration process creates calcium-silicate-hydrate gel. Concrete composed of a phase without clear, definite shape or form, nanometer to micrometer size crystals and bound water, during this stage, calcium-silicate-hydrate gel grip concrete together (15).

2.1. Calcium-Silicate-Hydrate (C-S-H) Gel Its Structure, Importance and Behavior in Concrete

The chemical reactions between cement, water and resulting products that are produced create a material that is highly complex. The dominant component, C-S-H gel, has a local structure of a precipitate with nanoscale features that are difficult to model and understand (14). The size of the calcium silicate hydrate (C-S-H) phase, the crucial component liable for strength and other properties in cementitious systems, lies in the few nanometer range. The structure of C-S-H is akin to clay, with thin layers of solids separated by gel pores filled with interlayer and adsorbed water (16). It is learnt that during hydration process, the C-S-H is the strength segment and the by-product CH is not having any cementitious properties, easily be dissolved.

2.2. C-S-H Gel Future Scope for Research

In the recent development trend sustainability is the main disquiet which increases to study concrete structure at nano level & development that takes place due to incorporation of nano materials (13). Recent development in experiment and theory based nano engineering and nanoscience has unlocked the doors in material science. From the experiment and study it is concluded that two type of calcium - silicate-hydrate (C-S-H) gel structure exists, one with low density and other with high density. But, it is still not clear how this two type of C-S-H gel structure affects the mechanical properties of concrete material (15).

3. Concrete and Its Environmental Issues

Concrete consists of Ordinary Portland cement, Coarse aggregate, fine aggregate , admixture and water. The concert is nanostructured, multi-phase composite material that ages over time (17). Cement is the main ingredient of concrete, which account for 10 to 15 percentages of concrete, one of the largest commodities consumed by mankind, is obviously the product with great potential but not completely explore (18). In 2011, the expected total worldwide production of cement was 3,400 million tonnes and it is expected to increase the total worldwide production of cement to 6000 million tonnes up to 2050 (14). The major advantages of this material are: availability of raw materials for production all over the world, low cost, setting at room temperature, simplicity of construction, readily available properties and performance data for design and construction. In addition the modern day concrete has a very good performance record for a period of more than 175 years (5).

Manufacturing of cement contributes greenhouse gases, both directly through the production of carbon dioxide when calcium carbonate is heated, producing lime and carbon dioxide and indirectly through the use of energy, particularly if the energy is sourced from fossil fuels (19). The cement industry produces about 5% of global man-made CO2 emissions (20), of which 50% is from the chemical process, and 40% from burning fuel. The amount of CO2 emitted by the cement industry is nearly 900kg of CO2 for every 1000kg of cement produced.

4. Ongoing Problem with Concrete Industry

1. Although hydration of cement is taking place with byproducts, materials are available in concrete, the reactions within the concrete as it sets and strengthens are difficult to control.
2. The main problem during the fresh sage and hardened stage is the cracks and problems related to cracks. Cracks in the concrete structure are created due to the chemical reaction of alkali–silica (alkali that is hydroxide ions present in cement pore and silica present in the aggregate).
3. Gases through this micro cracks take entry into the concrete structure, which leads to corrosion problem in the reinforcement of concrete.
4. Due to cracks, expansion and shrinkage of concrete take place at a later stage due to sulfate attack, which cause disintegration in concrete and chemical leaching.
5. By product of hydration i.e. calcium hydroxide (CH)

reduces the total pore volume by converting some of the liquid water into solid form, also it surround the cement particle, if this CH comes in contact with fresh water it dissolve and increase the porosity of concrete and reduce durability also.

5. Amalgamate Nanotechnology and Concrete and Its Affirmation

Nanotechnology is widely considered as one of the 21st century's important technologies, and its trade and industrial importance are gradually on the rise (21). The role of nanotechnology in conceiving of innovative infrastructure systems has potential to revolutionize the civil engineering practice (20). Conventional concrete improved by applying nanotechnology aims at embryonic a innovative, clever, eco- and environment - friendly construction material towards the green structure. At the nano scale, material properties are altered from that of larger scale (22). One of the fundamental aspects of nanotechnology is its interdisciplinary nature and there has already been crossed over research between the mechanical modelling of bones for concrete engineering (16). Concrete is, after all, a macro-material strongly influenced by its nano-properties and understanding it at this new level is yielding new avenues for improvement of strength, durability, improvement in stress-strain behaviour, ease of placing, etc. (7). Significant need of the concrete as a construction material is to significantly increase reliability because it is estimated that up to 10% of concrete placed in a given year fails prematurely or is below standard from the beginning. Even a small reduction in the number of problems using nanotechnology, amount to significant economic savings and performance benefits (12).

As computing capabilities grow and nano techniques are developed, we now are starting to improve the tools and skills that we need to take a fundamental look at the hydrated cementitious system (12). Using the nanotechnology, it is therefore viable to consider how to modify the system of cement based materials to address the issues confronting working construction sites like shrinkage and controlling the degree of hydration (12). Analysis of concrete is being done at the Nano-level in order to understand its structure using the various techniques developed for study at that scale, such as Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and Focused Ion Beam (FIB) (3).

These interactions offer the possibility of modifying cement reactions, creating new surface chemistries (referred to a nanoscience), developing new products for the concrete industry (referred to as nanotechnology), and allowing a more controlled and ecologically friendly manufacturing route to cement and concrete.

6. Conclusion

The development of nanotechnology-based concrete materials requires a multididirective approach, consisting of members having knowledge of material of concrete like-person aware of materials, chemical, physics and civil engineers. The application of nanotechnology in construction presents a myriad of opportunities and challenges. The use of micro nano materials (MNMs) in the construction industry should be considered not only for enhancing material properties and functions, but also in the context of energy conservation (13). Following are the key breakthroughs in concrete technology that are most likely to result from the use of nanotechnology.

Evolve high-performance cement and concrete materials as measured by their mechanical and durability properties. Promotion of sustainable structures and concrete materials by way of engineering for different adverse environments, reducing energy consumption during cement production, and enhancing safety .Promotion of smart concrete materials through the amalgamation of Nanotechnology origin self-sensing and self-powered resources and cyber infrastructure technologies. Evolve of novel concrete materials through nanotechnology-based innovative processing of cement and cement paste. Promotion of fundamental multiscale model(s) for concrete through advanced characterization and modeling of concrete at the nano -, micro -, meso-, and macro scales.

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