Nanotechnology and Its Role in Sustainable Development in Construction Industry

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***Abstract*— Nanotechnology is one of the emerging technologies having a wide range of multidisciplinary applications. In the construction industry, Nanotechnology is poised to bring about revolutionary changes by way of developing innovative materials and processes. This paper focuses on the role of Nanotechnology in furthering sustainable development in the construction industry at large through enhancement of material properties by using Nanoparticles and modification in processes and procedures. An overview of influence of Nanoparticles as supplementary cementitious materials such as Nano SiO2, NanoAl2O3, Nano TiO2, Nano clay and the modification in curing practices on Ultra High-Performance concrete (UHPC) and self-healing capacity of High-Performance concrete has been made. The effects of different Nanomaterials on alkali activated binders and their advantages and disadvantages are also discussed. Properties and prospects of Polymer Nano composite coating for protection against corrosion is outlined. Performance enhancement through Nano modification on asphalt mixture is also summarized. It also throws light on its application for building energy efficiency systems and self-cleaning efficiency of Nanoparticles. Paper concludes with the necessity to address and manage risks related to the use of Nanomaterials in the construction industry.**

Keywords*— Nanotechnology, Nano silica, Alkali activatedbinders, Nano modification on asphalt mixture

I. INTRODUCTION

Nanotechnology is an emerging technology that has caught the attention of researchers from both developed and developing countries. The applications of nanotechnology are varied and have been realized in areas of energy conservation, environment protection, electronics, information technology, materials and material composites and so on. The main aim of this paper is to present an overall literature review on nanomaterial-based application in construction material composites such as Ultra High Performance Concrete (UHPC) and High Performance Concrete (HPC) as well as performance enhancement through nano modification on asphalt mixture, nanomaterials utilized for the modification and the scope of enhancement of various material properties through incorporation of nanoparticles. With regard to developing construction materials with enhanced mechanical properties and increased durability, efforts are being taken in the past decade by researchers all over the world. Studies reveal that, by using nano silica in concrete better durability, mechanical, physical and microstructure properties can be obtained. Nanotechnology development will definitely affect the field of construction and construction materials. Nanomaterials can be defined as the particles with particle size between 1 to 100 nm. Based on the dimensions of the nano materials, they can be divided into four groups. Zero- dimensional (0D), one dimensional (1D), two dimensional (2D), three dimensional (3D) Nanoparticles. A 0D dimensional Nanoparticle is defined as a particle with all its dimensions subject to nano scale. This group includes nanoparticles, nanoclusters and nanocrystals. Nano SiO_2, TiO_2, ZnO and $CaCO_3$ nanoparticles are categorized as 0D. A one dimensional nanoparticle can be described as having two dimensions in nano scale with the other dimension reaching above the nano scale. Nanotubes, nanofibers, Nano rods and nanowires belong to this category. A 2D nanoparticle is originally a sheet with its thickness in the nanoscale and its sides spreading beyond the “nano” criterion. This group covers nanofilms, nanolayers, and nanocoatings. Three-dimensional nanomaterials include powders, fibrous, multilayer, and polycrystalline materials in which the 0D, 1D, and 2D structural elements are in close contact.

Role of nanoparticles in Ultra High Performanceconcrete (UHPC)

Ultra High Performance Concrete (UHPC) is a composite material, the microstructure of which is improved through nano filler effect and the pozzolanic reaction of the large quantity of cement and silica fume as binder. UHPC is known for its very high compressive strength to the order of above 150 MPa. The stiffness and strength of Interfacial Transition Zone (ITZ) between aggregates and binding paste matrix is also enhanced in addition to the improvement of microstructure. Due to the hydration reaction between water and cement, a large amount of $Ca(OH)_2$ is produced in the crystal form, and gets arrayed in the interfacial transition zone. Silica materials like silica fume and nano silica can react with $Ca(OH)_2$ and calcium-silicate-hydrate (C-S-H) gel is produced. In this manner, the $Ca(OH)_2$ crystals are absorbed and reduced to C-S-H gel. The C-S-H gel fills the voids hence improves the density of ITZ [1] Large capillary pores get refined by nano silica due to the combined contribution of nano filler effects and the pozzolanic reaction. It has been reported that the pozzolanic reaction of silica with Ca $(OH)_2$ is more efficient with nano silica with which it forms C-S-H gel and at final stages increases density of concrete) Moreover, some researchers like [2]agreed that contribution of Silica Fume and Nano Silica with concrete constituents would save the cement that accounts for sustainability of economic and environmental development.

Curing Regimes

During curing of UHPC at standard temperatures, hundreds of millions of fine particles of supplementary cementitious materials such as silica fume, fly ash etc. which chemically do not react, fill the spaces between cement particles called the micro filler effect / particle packing, mechanically contribute to increasing the strength characteristics as they form a compact structure of the cement matrix. When the curing temperature was 20^0C, the pozzolanic activity is weak and by prolonging the curing age reasonably, the compressive strength of UHPC can go up to 200 MPa [9] It has been observed that addition of nano $CaCO_3$ has an influence on the increase of compressive strength and flexural strength of UHPC after hot water curing.

[10] High temperature curing accelerates the hydration of cement and improves the secondary hydration between supplementary cementitious materials and $Ca(OH)_2$. It was found that the presence of MgO in silica fume after curing at high temperature increased the compressive strength up to 18.6% [11].Steam curing at 90^0C for 12 days improved the compressive strengths of all mixtures with respect to standard room temperature curing. Research shows the contribution of the autoclave to the compressive strength of concrete [12] It was only through 8 hr autoclave curing that over 200 MPa compressive strength could be achieved for UHPC with 3% or 4% of fibers.

Effect of Nanoparticles on the Self-Healing Capacity of High Performance Concrete (HPC)

In the specific field of construction materials, self-healing may be accomplished by components already present in the cementitious matrices or caused by engineered additions specific for this action. Depending on its origin/nature, self- healing concrete can be classified as autogenous or autonomous. [14]. Autogenous healing is an intrinsic characteristic of concrete that heals small cracks mainly by further hydration of cement and/or precipitation of $CaCO_3$, although swelling of the matrix and blocking of the crack due to debris present in the ingress water or loose concrete particles can also play a healing role. On the contrary, in the autonomous approach the healing is caused by engineered addition specific for this action to the cementitious matrix by introducing encapsulated polymers or minerals or bacteria. Studies reveal that healing of cracks through autonomous strategies is higher than by autogenous.

Self-healing Systems based on Nanoparticles used in Cementitious Materials (binders)

For the specific case of high-performance concrete (HPC) an autogenous self-healing mechanism is observed because of the presence of discontinuous and randomly dispersed fibre reinforcement in the concrete matrix. Taking into account the self-healing capacity of HPC, their self-healing potential can be improved by the incorporation of an autonomous self- healing system that allows the healing of wider cracks.

There are two ways where silica nanoparticles play an active role in the self-healing process. In accordance with findings of Van Tittelboom in the first one, bacteria suspended in salt solution when added to a commercial silica nanoparticle dispersion, it was found to effectively seal 0.3mm wide cracks after the injection of the suspension, into the cracks and immersing the samples into an equimolar urea calcium solution to promote $CaCO_3$ precipitation [16]. In the second one, silica nanoparticles functionalized with amine groups and silica microcapsules containing epoxy resin were used as addition for cement composites. During the hydration process the nanoparticles reacted with Ca $(OH)_2$ to give place to amine functionalized C-S-H. The objective of the functional group was to serve as the curing agent for the epoxy resin contained in the microcapsules, which should be liberated in the event of formation of a crack. This method was effective in sealing of wider cracks of UHPC under different environmental conditions.

Another approach found in the literature is that the crack healing phenomenon developed is based on microbial activity of bacteria and they were introduced in concrete by direct incorporation or immobilization of graphite Nano platelets. Moreover, bacteria immobilized in graphene Nano platelets showed high healing efficiency in pre-cracked samples.[17]

Application of Nano Materials in Alkali Activated Materials (AAM)

Alkali Activated Materials have drawn great attention because of their superior properties and environmental benefits. Global warming potential of Alkali activated concrete is 70% lower compared to Portland cement concrete [18]. Certain properties of materials would be affected when their sizes reduce to the nanorange, for example, size can strongly impact melting point, fluorescence, chemical reactivity, electrical conductivity, etc., due to quantum mechanical effects or other physical effects (e.g., high specific surface area) [19] . The amount of atoms at the surface compared to the number of atoms in the inner part becomes significant for nanomaterials, increasing the amount of material exposed to the surrounding medium, increasing the reactivity of nanomaterials [20]and one typical example is the increased solubility of silica with the decrease of its particle size.

In the past decade research has been carried out to investigate the influence of nanoparticles on key properties of Alkali Activated Materials including workability, setting, density and porosity, microstructure, mechanical properties, durability, shrinkage, fire resistance etc. The concept of Alkali Activated Materials uses alkali solutions or salts to dissolve and activate wastes or industrial by products to obtain sustainable building materials. Addition of Nano silica has a definite contribution to the mechanical property of fly ash based geopolymer [21], but much less significant contribution to slag-based alkali activated binder [22]. It has also been reported [23] that nano Al_2O_3 contributes to reduction in setting time, improved bonding of geopolymer and concrete substrate. It was also observed that nano TiO_2 enhances the strength and reduces the shrinkage with a dosage of 0.5% by mass [24]. It was also reported that adding 1% to 3% nano clay reduces the porosity and water absorption up to 7.21% and 17.35% respectively [25]. Experimental development of fly ash based geopolymer applying reduced graphene oxide revealed that graphene oxide refines the microstructure and improves mechanical properties of the geopolymer.[26]. In the future research, more efforts shall be spent on understanding of the interaction between nanomaterials and alkali activation. Besides, researches should also be focused on the durability related issues and the relationship between nanomaterials and various durability aspects

As far as disadvantages are concerned, application of nano materials with alkali activated material increases the water demand because of the high specific area of the nano materials and as a result of which workability is reduced. Therefore, the selection of appropriate super plasticizers is crucial in achieving the desired workability.

Property enhancement with the nano mineral materials modification

In order to face new challenges arising out of development of modern society, the traditional transport system should be given a facelift. Nanotechnology has proved to be a promising method for modification of the traditional material with nano mineral materials. The enhancement on the mechanical performance of the asphalt mixture is mainly due to the filler effect of the nanomaterials. The nanomaterials applied in asphalt materials mainly include nano mineral [27] and nano carbon materials (carbon nanotube and exfoliated Graphite Nano Platelets (xGNP)). One main issue with the asphalt mixture is the low stiffness[28],[29]compared to the Portland cement concrete, which can lead to instability at high temperature [30]and lead to high permanent deflection. [31] It is expected that the added nanomaterials can behave as fillers [32] to enhance its stiffness and deal with these issues. However, the added nanomaterial can alsodeteriorate its resistance to low-temperature cracking. Hence the mixture design optimization is recommended to achieve the nano modified asphalt mixture with appropriate performance. The added nano carbon materials can enhance the thermal conductivity, electrical conductivity, and optical absorbance ability of the asphalt mixture materials, which can promote the self-healing or self-sensing functions with the absorbed electromagnetic radiation energy through conductive media. The asphalt mixture with enhanced performance can prolong its service life, reduce the demand for asphalt materials and further lower its life cycle cost [33].

Effect of Nano fillers on the Anticorrosive and AntiwearProperties of Coatings

The controlled addition of nanoparticles to the coatings has become a good alternative to obtain the so-called nano coatings in order to improve their effectiveness in corrosion protection, in addition to various other properties. In thecase of organic matrices, it is reported that epoxy based coatings [34] containing metal oxides as nanoparticles significantly improved the corrosion resistance of the coated steel, with the Fe_2O_3 and halloysite clay nanoparticles being the best. For polyester coatings, [35] reported that the embedding nano clay led to the absence of pores and flaw in coatings as well as creating a protective barrier against corrosive electrolytes penetration; thus the corrosion resistance of nanocomposite coatings was higher than the pure coatings. They also reported that, with the presence of nano clay, the wear rate of nanocomposite coating was much lower than neat coating because of relatively denser structure in the presence of nanoparticles. Currently the study using nanomineral materials mainly focuses on the application of nanoclay and the study on other nanomineral materials is limited. However it has been learnt that the nano$CaCO_3$ and nanohydrated lime can have both high temperature and low temperature performance, which behaves better than the nanoclay materials. More studies are needed to unveil this mechanism.

Application of nanoparticles in building energy efficientsystems and its self-cleaning efficiency

Energy consumption has become an urgent issue not only for the global environment, but also for people's lives. Among total energy consumptions, buildings take nearly 40%. For buildings, energy exchange through windows accounts for over 50% of the energy consumed through a building's envelope by means of conduction, convection, and radiation [36].To reduce energy consumption new structures for glass surfaces have to be developed in order to enhance the thermal insulation properties. A simple way in which the thermal exchange can be reduced is to use thin film coatings on building windows in order to limit the amount of solar radiation entering or blackbody radiation leaving a building.

Chromogenic materials that exhibit obvious changes in their optical properties have been intensively developed to modulate the solar radiation. Amidst different types of smart coatings, thermochromic coatings typically based on a Vanadium dioxide (VO_2) functional layer, wherein responses are stimulated by variation in temperature has attracted great attention due to its self-adaption with environmental temperatures.[37] In general, there are mainly two forms of VO_2-based thermochromic coatings: flexible foils and multi-layered films which are directly fabricated on glasses. Flexible foils constructed by VO_2 nanoparticles and polymer composite foil are usually fabricated by solution methods. Multilayered films are made by direct deposition methods such as sputtering, evaporation, and chemical vapor depositions. VO_2 can be employed to intelligently adjust the near infrared (NIR) radiation according to the environmental temperature. Using VO_2-based thermochromic coating on glass can help to make people's life more comfortable and energy-efficient.

In general, self cleaning systems are classified into two types: a photo catalyst system with titanium oxide [38] and an alkyl silicate system [39], [40]. Although the photo catalyst system has high hydrophilicity, it cannot be used for organic paints because of its decomposing nature. In this system, two additional layers in addition to the existing paint layer (a protective layer and a photo catalyst layer) are required. Therefore, the photo catalyst system is a little expensive. On the other hand, the alkyl silicate system is suitable for ordinary paint and the self-cleaning layer with a base coat binder resin is applied by a single coat process. An acrylic silicon polymer based resin is useful for the formulation of the alkyl silicate self-cleaning paint which involves simple coating process and high cost performance.

CONCLUSION

The potential utility of nanoparticles has been explored since long, but the big difference is that now we have a better understanding of the physical and chemical phenomena of nanotechnologies. Consequently, materials with new properties can be formulated and produced, allowing researchers to take advantage of the special properties that occur in the nanoscale. Nanomaterials are new emerging materials in various fields including the field of Civil Engineering and have resulted in a variety of products and applications. Among the various benefited industrial directions, the construction sector has observed significant progress in the past few decades. Thanks to the extra-brought properties, the application of nanomaterials in construction materials, such as reduction in setting time, increased bonding in cement, refinement of microstructure, increased density, reduction in porosity, improvement in flexural and compressive strength, self-healing of cracks, reduction in shrinkage, prolonged service life in concrete which leads to reduced life cycle cost and reduced cement consumption bringing forth the environmental protection. Corrosion protection, thermal insulation, reduced energy consumption are the added benefits of addition of nanoparticles in coating and paints and enhancement of the stiffness, reduction in permanent deflection and high temperature stability of the asphalt mixture etc are becoming more and more popular. However, considering the toxicity and carcinogenicity of nanoparticles and the health hazards it can produce in the workers, nanomaterials need to be used with utmost caution and adequate protection. It is essential to focus on risk assessment and focus on the process of risk management within occupational settings and environment.

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