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An Exploratory study of Nanotechnology in Construction Engineering

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ABSTRACT

Nanotechnology is an extremely wide term, Nanotechnology is one of the most active research areas that encompass a number of disciplines, including civil engineering and construction materials. It seems to hold the key that allows construction and building materials to replicate the features of natural systems improved until perfection for millions of years. Traditionally, nanotechnology has been concerned with developments in most of the fields like microbiology, medicine, electronic, chemical, and materials sciences. However, the potential for application of many of the developments in the nanotechnology field in the area of construction engineering has been growing. Nanoparticles also have an increased surface area relative to their volume, making them especially reactive and useful in energy storage, for making composite materials, or as drug delivery devices. Nano materials are also able to be integrated with biological materials, producing new structures that have properties of both types of materials. There are two main types of approaches to nanotechnology: The "top-down" approach and the "bottom-up" approach. The "top-down" approach involves taking larger structures that are either reduced down in size until they reach the nano-scale, or are deconstructed into their composite parts. On the other hand, the "bottom-up" approach is where materials are constructed from the atomic or molecular components.

Key Words: materials, structures, nanoparticles, Titanium dioxide,

I. INTRODUCTION

Nanotechnology in Civil Engineering Nano technology has several applications in the engineering field, especially in the area of civil engineering [1]. An enormous number of materials can be enhanced by the use of nanotechnology, some of which include glass, concrete, and steel. Nanoparticles can also be used in coatings such as paints to give the coating "…self-healing capabilities and corrosion protection under insulation. Since these coatings are hydrophobic and repel water from the metal pipe and can also protect metal from salt water attack." [2]. The amalgamation of nanotechnology in civil engineering and construction is immensely useful to the field. Nanotechnology can be used to increase the life of concrete, create fire-resistant materials such as steel, and give building materials qualities such as "selfhealing" and "self-cleaning." On a personal level, we are very interested in the design, 162 European Journal of Sustainable Development and engineering of buildings and other infrastructure. As a child we use to design and make buildings out of paper, and the idea of the design and construction of buildings has always been of interest to me.

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As a future engineer we would like to be able to do research on finding new materials to help create stronger, better, longer lasting buildings and structures [3-4]. Nanotechnology can, and has revolutionized the way civil engineering is conducted by opening new possibilities for materials and is an important aspect to the field of civil engineering. It is for this reason that we believe that nanotechnology should be more widely incorporated into engineering curriculums around the country. Currently, only a few colleges and Universities teach nanotechnology within their engineering programs, or even offer a degree in nanotechnology. This needs to be changed, especially for the field of civil engineering as nanotechnology is vital to the advancement of the field.

Nanotechnology is one of the most active research areas that include a number of disciplines including civil engineering and construction materials. Nanotechnology is the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions. Nanotechnology encompasses two main approaches: (i) the ‘‘topdown” approach, in which larger structures are reduced in size to the nanoscale while maintaining their original properties or deconstructed from larger structures into their smaller, composite parts and (ii) the ‘‘bottom-up” approach, also called ‘‘molecular nanotechnology” or ‘‘molecular manufacturing,” in which materials are engineered from atoms or molecular components through a process of assembly or self-assembly [5-6]. Traditionally nanotechnology has been concerned with developments in the fields of microelectronics, medicine and material sciences. However, the potential for applications of many developments in the nanotechnology field in the area of construction engineering is growing. The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry is making the nanotechnology aggressive and evolutional.

There are many potential areas where nanotechnology can benefit construction engineering like its applications in concrete, structural composites, coating materials and in nano-sensors, etc. Nanotechnology products can be used for design and construction processes in many areas. The nanotechnology generated products have unique characteristics, and can significantly fix current construction problems, and may change the requirement and organisation of construction process [7-8]. The recent developments in the study and manipulation of materials and processes at the nanoscale offer the great prospect of producing new macro materials, properties and products.

But till date, nanotechnology applications and advances in the construction and building materials fields have been uneven. Exploitation of nanotechnology in concrete on a commercial scale remains limited with few results successfully converted into marketable products. The main advances have been in the nanoscience of cementitious materials with an increase in the knowledge and understanding of basic phenomena in cement at the nanoscale.

II. NANOTECHNOLOGY AND CONCRETE

Concrete, the most ubiquitous material in the world, is a nanostructured, multi-phase, composite material that ages over time. It is composed of an amorphous phase, nanometer to micrometer size

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crystals, and bound water. The amorphous phase, calcium–silicate–hydrate (C–S–H) is the ‘‘glue” that holds concrete together and is itself a nanomaterial. Viewed from the bottom-up, concrete at the nanoscale is a composite of molecular assemblages, surfaces (aggregates, fibres), and chemical bonds that interact through local chemical reactions, intermolecular forces, and intraphase diffusion. Properties characterizing this scale are molecular structure; surface functional groups; and bond length, strength (energy), and density. The structure of the amorphous and crystalline phases and of the interphase boundaries originates from this scale.

The properties and processes at the nanoscale define the interactions that occur between particles and phases at the microscale and the effects of working loads and the surrounding environment at the macroscale. Processes occurring at the nanoscale ultimately affect the engineering properties and performance of the bulk material.

There are two main avenues of applications of nanotechnology in concrete research;the nanoscience and nano-engineering[9-10]. Nanoscience deals with the measurement and characterization of the nano and microscale structure of cement-based materials to better understand how this structure affects macroscale properties and performance through the use of advanced characterization techniques and atomistic or molecular level modeling. Nano-engineering encompasses the techniques of manipulation of the structure at the nanometer scale to develop a new generation of tailored, multifunctional, cementitious composites with superior mechanical performance and durability potentially having a range of novel properties such as: low electrical resistivity, self-sensing capabilities, self-cleaning, self-healing, high ductility, and self-control of cracks. Concrete can be nano-engineered by the incorporation of nanosized building blocks or objects (e.g., nanoparticles and nanotubes) to control material behavior and add novel properties, or by the grafting of molecules onto cement particles, cement phases, aggregates, and additives (including nanosized additives) to provide surface functionality, which can be adjusted to promote specific interfacial interactions.

At the basic science level, much 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). This has come about as a side benefit of the development of these instruments to study the nanoscale in general, but the understanding of the structure and behaviour of concrete at the fundamental level is an important and very appropriate use of nanotechnology.

One of the fundamental aspects of nanotechnology is its interdisciplinary nature and there has already been cross over research between the mechanical modeling of bones for medical engineering to that of concrete which has enabled the study of chloride diffusion in concrete (which causes corrosion of reinforcement) [11-12]. 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 and monitoring.

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Crystallised C-S-H Atomic resolution

2*2 *µm²*

20*20 *nm²*

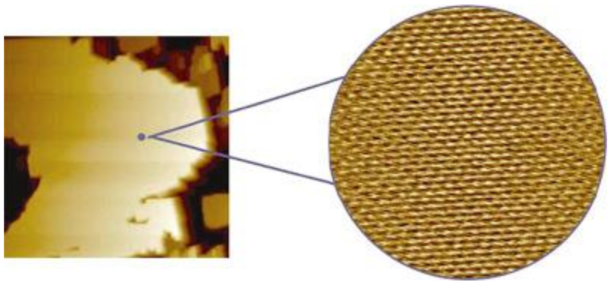

Fig 1. Nanoscale structure of C-S-H crystallized on calcite substrate and revealed by AFM

Nano-engineering, or nanomodification, of cement is a quickly emerging field. Synthesis and assembly of materials in the nanometer scale range offer the possibility for the development of new cement additives such as novel superplasticizers, nanoparticles, or nano reinforcements. These techniques can be used effectively in a bottom-up approach to control concrete properties, performance, and degradation processes for a superior concrete and to provide the material with new functions and smart properties not currently available. Engineering concrete at the nanoscale can take place in one or more of three locations: in the solid phases, in the liquid phase, and at interfaces, including liquid–solid and solid–solid interfaces. While nano-engineering of cement-based materials is seen as having tremendous potential, nonetheless, several challenges will need to be solved to realize its full potential, including the proper dispersion of the nanoscale additives, scale-up of laboratory results and implementation on larger scale, and a lowering of the cost benefit ratio.

A. Addition of nanosized and nano-structured materials

Nanosized particles have a high surface area to volume ratio, providing the potential for tremendous chemical reactivity. Much of the work to date with nanoparticles has been with nano-silica (nano-SiO_2) and nano-titanium oxide (nano-TiO_2). There are a few studies on incorporating nano-iron (nano-Fe_2O_3), nano-alumina (nano-Al_2O_3) , and nanoclay particles . Additionally, a limited number of investigations are dealing with the manufacture of nanosized cement particles and the development of nanobinders. Nanoparticles can act as nuclei for cement phases, further promoting cement hydration due to their high reactivity, as nano reinforcement, and as filler, densifying the microstructure and the ITZ, thereby, leading to a reduced porosity. The most significant issue for all nanoparticles is that of effective dispersion. Though it is particularly significant at high loadings, even low loadings experience problems with self-aggregation, which reduces the benefits of their small size and creates un-reacted pockets leading to a potential for concentration of stresses in the material.

Nano-SiO_2 has been found to improve concrete workability and strength, to increase resistance to water penetration, and to help control the leaching of calcium, which is closely associated with various types of concrete degradation. Nano-SiO_2, additionally, was shown to accelerate the hydration reactions of both C_3S and an ash–cement mortar as a result of the large and highly reactive surface of the nanoparticles. Nano-SiO_2 was found to be more efficient in enhancing strength than silica fume. Addition of 10% nano-SiO_2 with dispersing agents was observed to increase the compressive strength of cement mortars at 28 days by as much as 26%, compared

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to only a 10% increase with the addition of 15% silica fume. Even the addition of small amounts (0.25%) of nano-SiO_2 was observed to increase the strength, improving the 28 day compressive strength by 10% and flexural strength by 25%. It was noted that the results obtained depended on the production route and conditions of synthesis of the nano-SiO_2 (e.g., molar ratios of the reagents, type of reaction media, and duration of the reaction for the sol–gel method) and that dispersion of the nano-SiO_2 in the paste plays an important role. Nano-SiO_2 not only behaved as a filler to improve the microstructure but also as an activator to promote pozzolanic reactions.

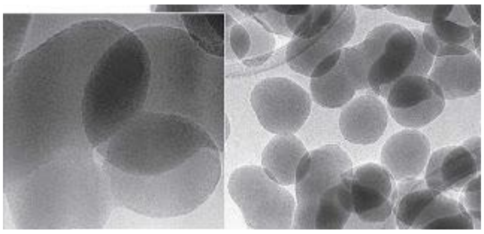

Fig 2. Spherical nano-SiO2 particles of uniform distribution observed using TEM

(of size 20 nm and 100nm)

Nano-TiO_2 has proven very effective for the self-cleaning of concrete and provides the additional benefit of helping to clean the environment. Nano-TiO_2 containing concrete acts by triggering a photocatalytic degradation of pollutants, such as NOx, carbon monoxide, VOCs, chlorophenols, and aldehydes from vehicle and industrial emissions. ‘‘Self-cleaning” and ‘‘de-polluting” concrete products are already being produced by several companies for use in the facades of buildings (e.g., the Jubilee Church in Rome, Italy). In addition to imparting self-cleaning properties, a few studies have shown that nano-TiO_2 can accelerate the early-age hydration of Portland cement, improve compressive and flexural strengths, and enhance the abrasion resistance of concrete. However, it was also found that aging due to carbonation may result in loss in catalytic efficiency.

Fig.3. Building made by using self-cleaning concrete (Church ‘‘Dives in Misericordia”, Rome, Italy)

Nano-Fe_2O_3 has been found to provide concrete with self-sensing capabilities as well as to improve its compressive and flexural strengths. Nano-Al_2O_3 has been shown to significantly increase the modulus of elasticity (up to 143% at a dosage of 5%) but to have a limited effect on the compressive strength. Nanosized cement particles and nanobinders have been proposed as a way to improve cement performance while reducing carbon emissions. Cement pastes made with nanosized cement particles have shown faster setting times and an increase in early compressive strength compared to pastes prepared with common. The concept of a nanobinder involves mechano-chemical activation that is obtained by inter-grinding cement with dry mineral additives in a ball mill. Mechano-chemical modification of cement with high volumes of blast furnace slag has been shown to increase the compressivestrength by up to 62%.

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B. Use of Nanoreinforcements

Carbon nanotubes/nanofibers (CNTs/CNFs) are potential candidates for use as nanoreinforcements in cement-based materials. CNTs/CNFs exhibit extraordinary strength with moduli of elasticity on the order of TPa and tensile strength in the range of GPa, and they have unique electronic and chemical properties.

CNTs/CNFs, thus, appear to be among the most promising nanomaterials for enhancing the mechanical properties of cement-based materials and their resistance to crack propagation while providing such novel properties as electromagnetic field shielding and self-sensing. Single-wall CNTs (SWCNTs), multi-wall CNTs (MWCNTs), and CNFs are highly structured graphene ring-based materials with very large aspect ratios (of 1000 or more) and very high surface areas. SWCNTs are single graphene cylinders and MWCNTs are multiple, concentric graphene cylinders coaxially arranged around a hollow core. Unlike CNTs, CNFs present numerous exposed edge planes along the surface that constitute potential sites for advantageous chemical or physical interaction.

Compared to CNTs, vapor grown CNFs have a lower production cost (about 100 times lower than SWCNTs) and are suitable for mass production. While CNTs/CNFs have been extensively studied in polymeric composites, their use in cement has, to date, remained limited. Most research efforts have focused on CNTs compared to CNFs and have been performed on cement pastes. One of the main challenges is the proper dispersion of CNTs/CNFs into cement paste, partly due to their high hydrophobicity and partly due to their strong self-attraction. Incorporating the unique mechanical properties of CNTs/CNFs in cement composites has proven to be rather complex and to date mixed results have been obtained. A number of methods have been investigated to improve dispersion and to activate the graphite surface in order to enhance the interfacial interaction through surface functionalization and coating, optimal physical blending, and the use of surfactant and other admixtures.

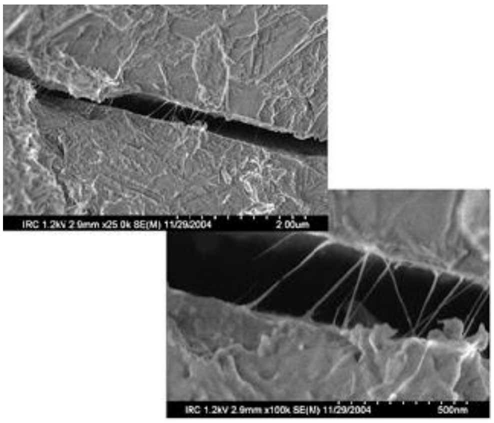

Fig.4 Crack bridging observed in cement-CNT composites.

(From the proceedings of ‘‘The 3rd International Conference on Construction Materials: Performance, Innovations and Structural Implications”)

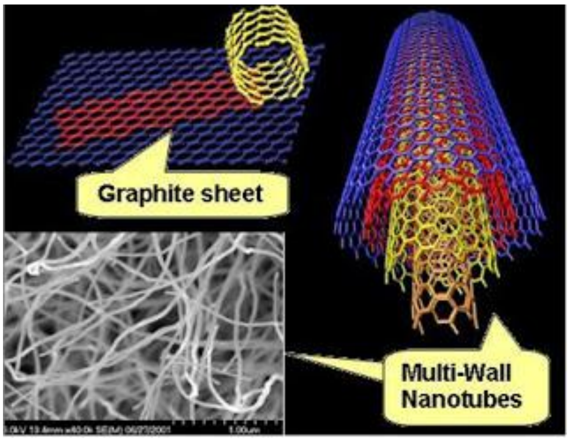

Fig.5. Graphite sheets of nanotubes

CNTs can affect early-age hydration and that a strong bond is possible between the cement paste and the CNTs. Their dispersion process consisted of sonication in isopropanol followed by cement addition, evaporation, and grinding, which produced cement particles coated with CNTs. Both MWCNTs and SWCNTs, when added to cement paste as a pre-mix with gum Arabic (a water-soluble gum used as a dispersing agent), were shown to increase the Young's modulus and hardness. But the mechanical properties got worsen when no dispersing agent was added. When MWCNTs was introduced as a water suspension with added surfactant admixtures, did not increase the compressive and bending strengths, though good dispersion was obtained. They also found the bonding between the MWCNTs and the cement matrix to be very weak, where, under tension, the MWCNTs were easily pulled off the matrix. But the combination of MWCNTs with polyacrylic-acid polymers found improved dispersion, good workability, and increased compressive strength. In mortar, a study using untreated CNTs and CNTs pre-treated with sulfuric and nitric acid found an increase in compressive strength up to 19% and in flexural strength up to 25% and that CNTs can decrease the electrical resistivity and improve the pressure sensitive properties of mortars. Oxidized multi-walled nanotubes (MWNT's) show the best improvements both in compressive strength (+ 25 N/mm^2) and flexural strength (+ 8 N/mm^2) compared to the reference samples without the reinforcement. It is theorized the high defect concentration on the surface of the oxidized MWNTs could lead to a better linkage between the nanostructures and the binder thus improving the mechanical properties of the composite rather like the deformations on reinforcing bars.

However, two problems with the addition of carbon nanotubes to any material are the clumping together of the tubes and the lack of cohesion between them and the matrix bulk material. Due to the interaction between the graphene sheets of nanotubes, the tubes tend to aggregate to form bundles or "ropes" and the ropes can even be entangled with one another. To achieve uniform dispersion they must be disentangled. Further more due to their graphite nature, there is not a proper adhesion between the nanotube and the matrix causing what it is called sliding. An alternative approach was recently developed by Cwirzen et al. for a hybridized Portland cement that incorporated CNTs and CNFs grown in situ on the cement particles using a modified chemical vapor deposition method. The resulting hybrid cement, called Carbon Hedge Hog (CHH), allows for a composite containing up to 20% CNTs/CNFs. No significant change in the flexural strength was found; however, the electrical conductivity was increased by one order of magnitude. The cost of adding CNT's to concrete may be prohibitive at the moment, but work is being done to reduce their price and at such time the benefits offered by their addition to cementitious materials may become more palatable.

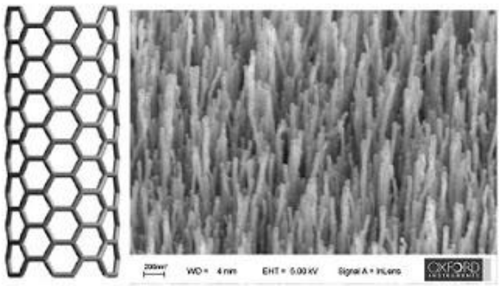

Fig.6 .Carbon nanotubes: right schematics; left microstructure

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III. NANOTECHNOLOGY IN STRUCTURAL COMPOSITES

A. Applications in Steel Structures, joint and welds

Fatigue is a significant issue that can lead to the structural failure of steel subject to cyclic loading, such as in bridges or towers. This can happen at stresses significantly lower than the yield stress of the material and lead to a significant shortening of useful life of the structure. The current design philosophy entails one or more of three limiting measures: a design based on a dramatic reduction in the allowable stress, a shortened allowable service life or the need for a regular inspection regime. This has a significant impact on the life-cycle costs of structures and limits the effective use of resources and it is therefore a sustainability as well as a safety issue. Stress risers are responsible for initiating cracks from which fatigue failure results and research has shown that the addition of copper nano particles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking. Advancements in this technology would lead to increased safety, less need for monitoring and more efficient materials use in construction prone to fatigue issues.

Current research into the refinement of the cementite phase of steel to a nano-size has produced stronger cables. High strength steel cables, as well as being used in car tyres, are used in bridge construction and in pre-cast concrete tensioning and a stronger cable material would reduce the costs and period of construction, especially in suspension bridges as the cables are run from end to end of the span. Sustainability is also enhanced by the use of higher cable strength as this leads to a more efficient use of materials

High rise structures require high strength joints and this in turn leads to the need for high strength bolts. The capacity of high strength bolts is realized generally through quenching and tempering. When the tensile strength of tempered steel exceeds 1,200 MPa even a very small amount of hydrogen embrittles the grain boundaries and the steel material may fail during use. This phenomenon, which is known as delayed fracture, has hindered the further strengthening of steel bolts and their highest strength has long been limited to somewhere around 1,000 to 1,200 MPa. Research work on vanadium and molybdenum nano particles has shown that they improve the delayed fracture problems associated with high strength bolts. This is the result of the nano particles reducing the effects of hydrogen embrittlement and improving the steel micro-structure through reducing the effects of the inter-granular cementite phase.

Welds and the Heat Affected Zone (HAZ) adjacent to welds can be brittle and fail without warning when subjected to sudden dynamic loading, and weld toughness is a significant issue especially in zones of high seismic activity. The current design philosophies include selective weakening of structures to produce controlled deformation away from brittle welded joints or the deliberate over-sizing of structures to keep all stresses low. Research has shown that the addition of nanoparticles of magnesium and calcium makes the HAZ grains finer (about $1/5^{th}$ the size of conventional material) in plate steel and this leads to an increase in weld toughness. This is a sustainable as well as a safety issue, as an increase in toughness at welded joints would result in a smaller resource requirement because less material is required in order to keep stresses within allowable limits.

Although carbon nano tubes (CNT's) have tremendous properties of strength and stiffness, they have found little application as an addition to steel as their inherent slipperiness (due to their graphitic nature) makes them difficult to bind to the bulk material and they pull out easily, rendering them ineffective. In addition, the high temperatures involved in steel manufacture and the effects of this on CNT's presents a challenge for their effective use as a composite component.

B. Nano-composites

Two relatively new products that are available today are Sandvik Nanoflex (produced by Sandvik Materials Technology) and MMFX2 steel (produced by MMFX Steel Corp). Both are corrosion resistant nano-composite, but have different mechanical properties and are the result of different applications of nanotechnology.

The modern construction requires steel of high strength and ductility. This has led to the use of low strength ductile material in larger sizes than would otherwise be possible with high strength brittle material and consequently it is an issue of sustainability and efficient use of resources. Sandvik Nanoflex has both the desirable qualities of a high Young's Modulus and high strength and it is also resistant to corrosion due to the presence of very hard nanometre-sized particles in the steel matrix. It effectively matches high strength with exceptional formability and currently it is being used in the production of parts as diverse as medical instruments and bicycle components, however, its applications are growing. The use of stainless steel reinforcement in concrete structures has normally been limited to high risk environments as its use is cost prohibitive. However, MMFX2 steel, while having the mechanical properties of conventional steel, has a modified nano-structure that makes it corrosion resistant and it is an alternative to conventional stainless steel, but widely not accepted due to its high cost.

C. Applications in Wood

Wood is also composed of nanotubes or "nanofibrils"; namely, lignocellulosic (woody tissue) elements which are twice as strong as steel. Harvesting these nanofibrils would lead to a new paradigm in sustainable construction as both the production and use would be part of a renewable cycle. Lignocellulosic surfaces at the nanoscale could open new opportunities for such things as self-sterilizing surfaces, internal self-repair, and electronic lignocellulosic devices. Due to its natural origins, wood is leading the way in cross-disciplinary research and modelling techniques. Firstly, BASF have developed a highly water repellent coating based on the actions of the lotus leaf as a result of the incorporation of silica and alumina nano particles and hydrophobic polymers. And, secondly, mechanical studies of bones have been adapted to model wood, for instance in the drying process. In the broader sense, nanotechnology represents a major opportunity for the wood industry to develop new products, substantially reduce processing costs, and open new markets for bio-based materials.

IV. APPLICATION OF NANOTECHNOLOGY IN CONSTRUCTION

Nanotechnology can be used for design and construction processes in many areas since nanotechnology generated products have many unique characteristics. These include products that are for: Lighter structure; Stronger structural composites e.g. for briges etc ; Low maintenance coating ; Improving pipe joining materials and

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techniques ; Better properties of cementitious materials ; Reducing the thermal transfer rate of fire retardant and insulation ; Increasing the sound absorption of acoustic absorber ; Increasing the reflectivity of glass.

There are large numbers of applications of nanotechnology in construction engineering/industry. Some of these applications are examined in detail below.

A. Concrete

Concrete is one of the most common and widely used construction materials. The rapid development of new experimental techniques makes it possible to study the properties of cementitious materials at micro/nano-scale.

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Research has been conducted to study the hydration process, alkali-silicate reaction (ASR), and fly ash reactivity using nanotechnology. The better understanding of the structure and behavior of concrete at micro/nano-scale could help to improve concrete properties and prevent the illness, such as ASR.

Addition of nanoscale materials into cement could improve its performance. Li (2004) found that nano-SiO_2 could significantly increase the compressive for concrete, containing large volume fly ash, at early age and improve pore size distribution by filling the pores between large fly ash and cement particles at nanoscale. The dispersion/slurry of amorphous nanosilica is used to improve segregation resistance for self-compacting concrete. It has also been reported that adding small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength.

Cracking is a major concern for many structures. University of Illinois Urbana-Champaign is working on healing polymers, which include a microencapsulated healing agent and a catalytic chemical trigger. When the microcapsules are broken by a crack, the healing agent is released into the crack and contact with the catalyst. The polymerization happens and bond the crack faces. The selfhealing polymer could be especially applicable to fix the microcracking in bridge piers and columns. But it requires costly epoxy injection.

B. Structural Composites

Steel is a major construction material. Its properties, such as strength, corrosion resistance, and weld ability, are very important for the design and construction. FHWA together with American Iron and Steel Institute and the U.S. Navy started to develop new, low carbon, highperformance steel (HPS) for bridges in 1992. The new steel was developed with higher corrosion-resistance and weld ability by incorporating copper nanoparticles from at the steel grain boundaries. Sandvik NanoflexTM is new stainless steel with ultra-high strength, good formability, and a good surface finish developed by Sandvik Nanoflex Materials Technology. Due to its high performance, Sandvik NanoflexTM is suitable for application which requires lightweight and rigid designs. Its good corrosion and wear resistance can keep life-cycle costs low. Attractive or wear resistant surfaces can be achieved by various treatments (Sandvik Nanoflex Materials Technology). MMFX2 is nanostructuremodified steel, produced by MMFX Steel Corp. Compared with the conventional steel, it has a fundamentally different microstructure- a

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laminated lath structure resembling "plywood". This unique structure provides MMFX2 steel with amazing strength (three times stronger), ductility, toughness, and corrosion resistance. Due to high cost, the stainless steel reinforcement in concrete structure is limited in high risk environments. The MMFX2 steel could be an alternative because it has the similar corrosion resistance to that of stainless steel, but at a much lower cost (MMFX Steel Corp.).

C. Coating

The coatings incorporating certain nanoparticles or nanolayers have been developed for certain purpose. It is one of the major applications of nanotechnology in construction. For example, TiO_2 is used to coat glazing because of its sterilizing and anti fouling properties. The TiO_2 will break down and disintegrate organic dirt through powerful catalytic reaction [10]. Furthermore, it is hydrophilic, which allow the water to spread evenly over the surface and wash away dirt previously broken down. Other special coatings also have been developed, such as anti-fraffiti, thermal control, energy sawing, antireflection coating.

D. Nanosensors

Nano and microelectrical mechanical systems (MEMS) sensors have been developed and used in construction to monitor and/or control the environment condition and the materials/structure performance. One advantage of these sensors is their dimension (10^{-9}m to 10^{-5}m) [12]. These sensors could be embedded into the structure during the construction process. Smart aggregate, a low cost piezoceramic-based multi-functional device, has been applied to monitor early age concrete properties such as moisture, temperature, relative humidity and early age strength development [13]. The sensors can also be used to monitor concrete corrosion and cracking.

The smart aggregate can also be used for structure health monitoring. The disclosed system can monitor internal stresses, cracks and other physical forces in the structures during the structures' life. It is capable of providing an early indication of the health of the structure before a failure of the structure can occur.

V. FUTURE CHALLENGE AND DIRECTION

As with most developing technologies, a major number of challenges exist during the initiation of the application of the technology into reality. It is important to be realistic and identify and plan for the limitations and challenges inherent in this process. In this section a short summary of selected challenges and limitations affecting application of nanotechnology in construction engineering are provided. The following main challenges and limitations can be defined: Fabrication, Health, Environment and Cost

A. Fabrication

Current efforts in the field of nanotechnology are focused on the fabrication, characterization and use of these materials on a nanoscale domain. This leads to most of the development work focusing on very small quantities of material that is typically far removed from the type of quantities required for typical construction infrastructure. One of the potential solutions to this is to focus on the nano materials to act as catalyser, thereby reducing the amount of nano material required substantially. Another viewpoint is that for many applications, the material does not necessarily have to be used on a nano scale to obtain a major improvement in benefits. This would be the case with reduction of the dimensions of cement, where

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a substantial improvement in strength can already be obtained through the large scale milling of the cement to a finer form than the traditional form. Although the cement may not be purely a nano material as yet, the benefits obtained would already be substantial [14].

B. Health

Nanotechnology based construction products might be harmful to health. For example, the nanotubes [15] might cause a lung problem to construction workers. In other words, it creates an environmental challenge to the construction industry as well.

VI. CONCLUSIONS

Based on the information discussed in this paper, the following conclusions are drawn:

- Nanotechnology is a rapidly expanding area of research where novel properties of materials manufactured on the nanoscale can be utilized for the benefit of construction infrastructure
- A number of promising developments exist that can potentially change the service life and life-cycle cost of construction infrastructure.

Based on the information discussed in this paper, the following directions are made:

- Focused research into the timeous and directed research into nanotechnology for construction infrastructure should be pursued to ensure that the potential benefits of this technology can be obtained to provide longer life and more economical transport infrastructure.

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