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Significance of Nanotechnology in Construction Engineering

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***Abstract*— Nanotechnology is one of the most active research areas that encompass a number of disciplines including civil engineering and construction materials. Traditionally, nanotechnology has been concerned with developments in the fields of microelectronics, medicine and materials sciences. However, the potential for application of many of the developments in the nanotechnology field in the area of construction engineering is growing. In this paper a broad overview of the potential application of various nanotechnology developments in the construction engineering field is discussed, and the potential for further basic research that may lead to improved systems is evaluated.**

***Index Terms*- Nanomaterials, Construction.**

I. INTRODUCTION

Nanotechnology is a field that is dominated by developments in basic physics and chemistry research [1], where phenomena on atomic and molecular level are used to provide materials and structures that perform tasks that are not possible using the materials in their typical macroscopic form. The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry are making the research on nanotechnology aggressive and evolutional [2]. Not surprisingly, it is observed that expenditure on nanotechnology research is significant. The U.S. National Nanotechnology Initiative (NNI) expenditures exceed $1 billion each year, with the President's 2008 budget for NNI at $1.5 billion. However, the research is mainly moving forward motivated by immediate profitable return generated by high value commercial products [3]. It has been established by study, nanotechnology in construction ranked 8 of 10 applications that most likely have impact in the developing world [4].

Nanotechnology covers the design, construction and utilization of functional structures with at least one characteristic dimension measured in nanometers [5]. The field of nanotechnology has developed in major leaps during the past 10 years. These developments were mainly driven by factors such as dedicated initiatives in the field (e.g. the National Nanotechnology Initiative) [5], improvements in characterization equipment and a new understanding into the chemistry and physics of matter on the nanoscale. Nanoscale science can be divided into three broad areas, e.g. nanostructures, nanofabrication and nanocharacterization with typical applications in nanoelectronics and life sciences & energy [5].

This article examines the potential areas where nanotechnology can benefit construction engineering. The data and information collected is from current literature. The purpose is to point out clear cut direction among the nanotechnology development areas where the construction process would immediately harness nanotechnology, by specifying clear recommendations. The information would be beneficial to both construction engineering education and research.

The rest of the paper is organized as follows. In Section II, detailed applications of nanotechnogy in construction engineering/industry are presented. Section III, presents the future challenges and directions. Finally, concluding remarks are offered in Section IV.

II. 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 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. Research has been conducted to study the hydration process, alkali-silicate reaction (ASR), and fly ash reactivity using nanotechnology [6]. 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.

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Addition of nanoscale materials into cement could improve its performance. In [7], 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 [8]. It has also been reported that adding small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength [9].

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 [8]. 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, high-performance steel (HPS) for bridges in 1992 [10]. 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 nanostructure-modified steel, produced by MMFX Steel Corp. Compared with the conventional steel, it has a fundamentally different microstructure- a 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, anti-reflection 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) [11]. 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 [12]. 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.

III. 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 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 [13].

B. Health

Nanotechnology based construction products might be harmful to health. For example, the nanotubes [14] might

cause a lung problem to construction workers. In other words, it creates an environmental challenge to the construction industry as well.

C. Environment

The effect of various nanomaterials on the natural environment is hotly debated in nanotechnology and environmental research. Various ongoing investigations focus on the uncertainty regarding the potential effects of materials that exist on the nanoscale with properties that are different than when using the material on a micro or macro scale [15]. Some work in this regard shows that the potential effects may be minimal [14]. As constructed infrastructure are provided in the natural environment, all materials used in the construction and maintenance of these facilities need to be compatible to the natural environment and their effects on the natural environment should not be negative. Typical potential problems in this regard include leaching of materials into groundwater, release of materials into airways through the generation of dust and exposure to potentially harmful materials during construction and maintenance operations. The nanotechnolgy becomes a double-edge sword to the construction industry. More research and practice efforts are needed with smart design and planning, construction projects can be made sustainable and therefore save energy, reduce resource usage, and avoid damages to environment.

D. Cost

The costs of most nanotechnology materials and equipment are relatively high. This is due to the novelty of the technology and the complexity of the equipment used for preparation and characterization of the materials [9]. However, costs have been shown to decrease over time and the expectations are that, as manufacturing technologies improve, these costs may further decrease. Whether the expected decreases will render the materials as run-of-the-mill construction engineering materials will have to be seen, and depends largely on the benefits rendered through the application of these materials. Current opinion is that in special cases, the materials will enable unique solutions to complicated problems that cause them to be cost effective, which will lead to large-scale application of these specific technologies. In other cases the traditional methods for treating the problem may still remain the most cost effective. It is the challenge to the construction engineer to solve real world transportation infrastructure problems and provide a facility to the general public at a reasonable cost.

IV. 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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