Nanotechnology in Civil Engineering and Its Reflection in Current Education

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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. The properties like self-sensing, self-rehabilitation, self-structural health monitoring, self-vibration damping, self-cleaning and self-healing are studied. Nanotechnology deals with understanding, controlling and manipulating matter at the level of individual atoms and molecules in the range of 0.1–100 nm (10^{-9} m). It creates materials, devices, and systems with new properties and functions. In civil engineering and construction, the nanotechnology is applied in (i) concrete for reducing segregation in self-compacted concrete; (ii) the use of nano sensors in construction phase to know the early age properties of concrete is very useful. The present paper reviews the state of the art on the use of nanotechnology in the field of civil engineering and construction and also discusses its future prospect. Following this the study were carried out in ductile structural composites along with its enhanced properties, low maintenance coatings, better properties of cementious materials, reduction of the thermal transfer rate of fire retardant and insulation, various nano sensors, smart materials, intelligent structure technology etc. Finally the future trend, potential and implications of nanotechnology development in civil engineering towards more economical infrastructure, low cost maintenance with longer durability are deliberated.

I. INTRODUCTION

A. Background

As people involved in construction, we are very familiar with the concept of getting raw materials, bringing them together in an organized way and then putting them together into a recognizable form. The finished product is a passive machine. It works and slowly decays as it is used and abused by the environment and the owners of the project. Construction then is definitely not a new science or technology and yet it has undergone great changes over its history. In the same vein, nanotechnology is not a new science and it is not a new technology either. It is rather an extension of the sciences and technologies that have already been in development for many years. The size of the particles is the critical factor. At the nanoscale (anything from one hundred or more down to a few nano meters, or 10^{-9} m) material properties are altered from that of larger scales. Another important aspect is that, as particles become nano-sized, the proportion of atoms on the surface increases relative to those inside and this leads to novel properties. It is these "nano-effects", however, that ultimately determine all the properties that we are familiar with at our "macro-scale" and this is where the power of nanotechnology comes in – if we can manipulate elements at the nano scale we can affect the macro properties and produce significantly new materials and processes.

B. What Is Nanotechnology?

Nano, which comes from the Greek word for dwarf, indicates a billionth. One nanometer is a billionth of a meter. Definitions of 'nanotechnology' vary, but it generally refers to understanding and manipulation of matter on the nanoscale, say, from 0.1 nm to 100 nm. The significance and importance of controlling matter at the nanoscale is that at this scale different laws of physics come into play (quantum physics); there are two ways to approach the nanoscale: shrinking from the top down, or growing from the bottom up. The 'top down' approach entails reducing the size of the smallest structures towards the nanoscale by machining and etching techniques, whereas the 'bottom up' approach, often referred to as molecular nanotechnology, implies controlled or directed self -assembly of atoms and molecules to create structures.

C. Nanotechnology In Construction

The use of nanotechnology in construction involves the development of new concept and understanding of the hydration of cement particles and the use of nano-size ingredients such as alumina and silica and other nanoparticles. With the help of nanotechnology, concrete is stronger, more durable and more easily placed, steel is made tougher, glass is self-cleaning and paints are made more insulating and water repelling.

1) Applications of Nanotechnology in Civil Engineering

Nanotechnology can be used for design and construction processes in many areas since nanotechnology generated products have many unique characteristics. These characteristics can, again, significantly fix current construction problems, and may change the requirement and organization of construction process. Some of its applications are examined in detail below:

2) Nanotechnolgy & Concrete

Concrete is one of the most common and widely used construction materials. Nanotechnology is widely used in studying its properties like hydration reaction, alkali silicate reaction (ASR) and fly ash reactivity [2]. Alkali silicate reaction is caused due to alkali content of cement and silica present in reactive aggregates. The use of pozzolona in the concrete mix as a partial cement replacement can reduce the likelihood of ASR occurring as they reduce the alkalinity of a pore fluid. Fly ash not only improves concrete durability, strength and, importantly for sustainability, reduces the requirement for cement, however, the curing process of such concrete is slowed down due to the addition of fly ash and early stage strength is also low in comparison to normal concrete. Addition of Nano-silica leads to the densifying of

the micro and nanostructure resulting in improved mechanical properties. With the addition of nano-SiO2 part of the cement is replaced but the density and strength of the fly-ash concrete improves particularly in the early stages. For concrete containing large volume fly ash, at early age it can improve pore size distribution by filling the pores between large fly ash and cement particles at Nano scale. The dispersion/slurry of amorphous nano-SiO2 is used to improve segregation resistance for self -compacting concrete. The addition of small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength. This can also improve the mechanical properties of samples consisting of the main Portland cement phase and water. Oxidized multi-walled nanotube (MWNT's) shows the best improvements both in compressive strength (+ 25 N/mm2) and flexural strength (+8 N/mm2) compared to the reference samples without the reinforcement.

Finally, fiber wrapping of concrete is quite common today for increasing the strength of preexisting concrete structural elements. Advancement in the procedure involves the use of a fiber sheet (matrix) containing nano-silica particles and hardeners. These nanoparticles penetrate and close small cracks on the concrete surf ace and, in strengthening applications, the matrices form a strong bond between the surface of the concrete and the fiber reinforcement.

3) Nanotechnolgy & Coatings

Coatings are routinely used as protective barriers against abrasion, chemical attack, hydro-thermal variations and to improve aesthetics. Currently, most of these coatings are in the micrometer range. New materials and techniques are being developed to develop nano-meter thick coatings that are durable and generate less heat due to reduced friction. Coatings could be self-cleaning and self-healing. In most cases the performance of these coatings are evaluated using experimental techniques. The major parameters evaluated are: durability of coatings under various exposure conditions, abrasion resistance, friction resistance, high temperature resistance and electrical characteristics. Performance of the (coating) film and the interface between the film and the parent material play important role in the overall durability of the system... For the nano coatings, the properties of the coatings themselves need investigation. Brittle coatings usually fail by cracking, delaminating and spalling rather than "wearing out". Robust analytical models are needed to predict the initiation and growth of cracks and their contribution to final degradation. Most existing coatings tend to accumulate grime reducing aesthetics. The deposited materials also degrade the parent surface over time. Coatings with a nano-scale of roughness that will repel water and dirt, modeled after the coating of the lotus leaf are being created. The lotus leaf has extraordinary ability to keep itself clean and dry. Now nanotechnology is being used to mimic the lotus leaf surface and create new products that outperform existing no-stick products. Typically, on a hydrophobic or water-repellent surface, particles of dirt are removed by moving water. But on a Lotus simulated surface, dirt particles are collected by water drops and rinsed off shows self-cleaning properties of a coating made using nano-particles. It can be seen that the coated surface is totally free of mold that is present adjacent to the coated surface [3].

4) Nanosensors

Nanotechnology enabled sensors/devices also offer great potential f or developing smart materials and structures which have 'self -sensing' and 'self -actuating' capability. The device used for air bags in cars is such an example. Nano and Micro electrical mechanical systems (NEMS & MEMS) sensors have been developed and used in construction to monitor and/or control the environment conditions (e.g. temperature, moisture, smoke, noise, etc.) and the materials/structure performance (e.g. stress, strain, vibration, cracking, corrosion, etc.) during the structure's life. Nano sensor ranges from 10^{-9} m to 10^{-5} m which could be embedded into the structure during the construction process. Cyrano Sciences has developed electronic noses based on an array of different polymer nanometer-thin film sensors [3]. Siemens and Yorkshire Water are developing autonomous, disposable chips with built-in chemical sensors to monitor water quality and send pollution alerts by radio [5]. 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 [3]. Also it can provide an early indication before a failure of the structure occurs.

5) Nanotechnology & Fire Protection & Detection

Fire resistance of steel structures is often provided by a coating produced by a spray-on cementious process. Current Portland cement based coatings are not popular because they need to be thick, tend to be brittle and polymer additions are needed to improve adhesion. However, research into nano-cement (made of nano-sized particles) has the potential to create a new model in this area of application because the resulting material can be used as a tough, durable, high temperature coating. This is achieved by the mixing of carbon nanotube (CNT's) with the cementious material to fabricate fiber composites that can inherit some of the outstanding properties of the nanotube such as strength. Polypropylene fibers are also considered as a method of increasing fire resistance and this is a cheaper option than conventional insulation. The use of processors in fire detection systems which are built into each detector head is fairly well established today. These improve reliability allowing better addressability and the ability to identify false alarms. The use of nanotechnology in the future through the development of nano-electromechanical systems (NEMS) could see whole buildings become networked detectors; as such devices are embedded either into elements or surfaces.

D. Future Challenge and Direction

While nanotechnology based construction products provide many advantages to the design and construction process, the production of these products, however, require a lot of energy. Also, the nanotube might cause a lung problem to construction workers. In other words, it creates an environmental challenge to the construction industry as well. Sustainability and environmental issues caused by growing economic development has gained intensive state wide and worldwide attention. Since the construction industry is heavily involved in the economic development and consumes great amount of resources and energy, its impact on environment is significant. Therefore, it is necessary and urgent to regulate the construction and its

related performance to sustainable manners. The nanotechnology 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. It is necessary to establish a system to identify the environmentally friendly and sustainable of construction nano materials and to avoid the use of harmful materials in the future.

E. Nanotechnology in Sustainability & the Environment

Sustainability is defined as "the ability which meets the needs of world's current population without compromising the ability of future generations to meet their own needs". Sustainable nanotechnology is the development of science and technology within the 1 – 100 nanometre scale, with considerations to the long-term economic viability and a sensible use of natural resources, while minimizing negative effects to human health and the environment. Sustainability and environmental concerns are closely linked and clean water is a key sustainable resource. Clean water has been one of the great leaps forward in public health provided by civil engineering and nanotechnology is being used to further this advance. In particular, iron nanoparticles, which have a high surface area and high reactivity, are being used to transform and detoxify chlorinated hydrocarbons (some of which are carcinogens) in groundwater. These nano-materials also have the potential to transform heavy metals such as soluble lead and mercury to insoluble forms, thus limiting their transport and contamination. "Nanotechnology is an enabling technology that is opening a new world of materials functionalities, and performances. But it is also opening new possibilities in construction sustainability. On one hand it could lead to a better use of natural resources, obtaining a specific characteristic or property with minor material use. It can (also) help to solve some problems related to energy in building (consumption and generation), or water treatment to mention only a few matters".

II. CONCLUSION

Research in nanotechnology that is related to construction is still in its infancy; however, this paper has demonstrated the main benefits and barriers that allow the effect of nanotechnology on construction to be defined. In conclusion, nanotechnology is disruptive and offers the possibility of great advances whereas conventional approaches, at best, offer only incremental improvements. Nanotechnology is not exactly a new technology; rather it is an extrapolation of current ones to a new scale and at that scale the conventional tools and rules no longer apply. Nanotechnology is therefore the opposite of the traditional top-down process of construction, or indeed any production technique, and it offers the ability to work from the "bottom" of materials design to the "top" of the built environment.

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