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REVIEW

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A REVIEW ON NANOTECHNOLOGY IN CIVIL ENGINEERING

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ABSTRACT: Nanotechnology is the science of engineering that deals with particle which are less than 100 nm in size. It is the study of manipulating matter on molecular and atomic scale. 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. Concrete is stronger, more durable and more easily placed, steel tougher and glass self-cleaning. At the nanoscale, familiar materials can have dramatically different properties -changes can affect colour, elasticity, strength, conductivity and other properties. Conventional concrete improved by applying nanotechnology provides a novel, smart, eco- and environment-friendly construction material towards the green structure. 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. Based on this view, research is going on evolve new or alternate material towards a green and sustainable solution. This paper present the possible use of nanotechnology in civil construction.
KEYWORDS- nanotechnology, strength, elasticity, nano-scale, molecular component

1 INTRODUCTION

Nanotechnology is the re-engineering of materials and devices by controlling the matter at the atomic level. Nanotechnology is not a new science and it is not a new technology. It is rather an extension of the sciences and technologies. At the Nano scale, material properties are altered from that of larger scales. 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. Following are the major application of nanotechnology in the field of (*i*) nanomedicine, (*ii*) Environment, (*iii*) Energy,(*iv*) nanobateries,
(v) Information and communication, (vi) Heavy industry etc. In recent years nanotechnology is also gaining popularity in the field of Civil Engineering andconstruction. The potential of nanotechnology in terms of the development of construction and building materials, namely:

- The use of nano-particles, carbon nano-tubes, and nano-fibers to increase the strength and durability of cementitious composites, as well as for pollution reduction.
- Production of cheap corrosion free steel.
- Production of thermal insulation materials with performance of 10 times the current commercial options.
- Production of coats and thin films with self-cleansing ability and self-colour change to minimize energy consumption.

Research and developments have demonstrated that the application of nanotechnology can improve the performance of traditional construction materials ,such as concrete, steel, glass, paint, coatings, insulating materials. Concrete is stronger, more durable and more easily placed, steel tougher and glass self-cleaning. Increased strength and durability are also a part of the drive to reduce the environmental footprint of the built environment by the efficient use of resources. This is achieved both prior to the construction process by a reduction in pollution during the production of materials (e.g. cement) and also in service, through efficient use of energy due to advancements in insulation.

Types of nano materials:

i) Titanium Dioxide (TiO_2)
ii) Carbon Nano Tubes (CNT's)
iii) Nano Silica (ns)

iv) Polycarboxilates
v) Nano Zro2, etc

1.1 *What Is Nanotechnology?*

Nano, which comes from the Greek word for dwarf, indicates a billionth. One nanometre is a billionth of a metre. Nanotechnology is the art and science of manipulating matter at the atomic or molecular scale and holds the promise of providing significant improvements in technologies for protecting the environment. The National Nanotechnology Initiative (NNI 2007) requires nanotechnology to involve all of the following:

- Research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1-100 nanometer (nm) range in any direction;
- Creating and using structures, devices, and systems that have novel properties and functions as a result of their small and/or intermediate size; and
- Ability to control or manipulate on the atomic scale

In nano-level, gravity becomes unimportant, electrostatic forces take over, and quantum effects come in. Furthermore, as particles become nano-sized, the proportion of atoms on the surface increases relative to those inside, and this leads to novel properties. Current researchers dealing with nano-science and nanotechnology are exploring these novel properties since at nano-scale; we can alter the macro-properties and produce significantly new materials and processes.

2 How nanotechnology use in civil engineering?

Nano technology has many applications in the engineering field, especially in the area of civil engineering. A vast number of materials can be enhanced by the use of nanotechnology, some of which include glass, concrete, and steel. For example, new structural materials with unique properties, lighter and stronger composites, fire insulator, sound absorber, low maintenance coating, water repellants, nano-clay filled polymers, self-disinfecting surfaces, UV light protector, air cleaners, nano sized sensors, ultra thin- strong- conductive wafers, solar cells etc to name a few.
Some of its applications are examined in detail below.

2.1 *Nano Concrete*

The most frequent and beneficial uses of nanotechnology in terms of civil engineering, is the use of it in concrete. Concrete “is a nano structured, multi-phase, composite material that age over time 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 . Silica (SiO_2) is present in conventional concrete as part of the normal mix. However, particle packing in concrete can be improved by using nano-silica which leads to a densification of the micro and nanostructure resulting in improved mechanical properties. Nano-silica addition to cement based materials can also control the degradation of the fundamental C-SH (calcium-silicate hydrate)reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability. Nano-silica particles, better known as silica fume, improve the overall panicle packing in concrete matrix resulting in very high compressive strengths (>15,000 psi1).
Titanium Dioxide Nano-powder added to concrete can give ability to break down dirt or pollution and then allow it to be washed off by rain water on everything from concrete to glass. TiO_2 is a white pigment and can be used as an excellent reflective coating. It is incorporated, in sun-block to block UV light and it is added to paints, cements and windows for its sterilizing properties since TiO_2 breaks down organic pollutants, volatile organic compounds, and bacterial membranes through powerful catalytic reactions. It gives self-cleaning properties to surfaces to which it is one of the most important applications of materials with photocatalytical properties concerns the destruction of fungi and bacteria. Fungi are responsible for mycotoxins growth (Reboux et al., 2010). Saito et al., (1992) studied the addition of TiO_2 powder with an average size 21 nm (30% rutile and 70% anatase) to a bacterial colony. The results showed that 60–120 mins were sufficient to destroy all the bacteria.

Carbon Nanotube addition to concrete can give the benefits to strengthen and monitor concrete. The addition of small amounts (1% wt.) of CNT’s can improve the mechanical properties of samples. Oxidized multi-walled nanotubes (MWNT’s) show the best improvements both in compressive strength (+ 25 N/mm2) and flexural strength (+ 8 N/mm2).

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 self-healing polymer could be especially applicable to fix the micro cracking in bridge piers and columns. But it requires costly epoxy injection.

2.1.1 *Benefits of using Nano materials in Concrete:*

Strengthened Concrete:

Carbon Nanotubes CNTs are added to the concrete mixture. Carbon Nanotubes are cylindrical with a diameter of 1 nanometer are theoretically 100 times as strong as steel but have only tested to be 8 times stronger. They are 1/6 the density of steel.

- Very high thermal conductivity along the tube axis
- The finished product has 1% CNT's to the 99% standard concrete.
- Can handle an additional 25 N/mm.

Strengthened concrete has 500% the tensile strength of normal concrete.

Self-Healing concrete

- Nano particles only allow small cracks to form.
- The particles mend themselves when they encounter water.
- The hydrogen in the water helps the particles to form the broken hydrogen bonds.
- Cracks will repair themselves when water is added

2.2 *Nano Glass*

Titanium dioxide (TiO_2) nano particles are used to coat glazing since it has sterilizing and anti-fouling properties. The particles catalyze powerful reactions that break down organic pollutants, volatile organic compounds and bacterial membranes. TiO2 is hydrophilic (attraction to water), which can attract rain drops that then wash off the dirt particles. Thus the introduction of nanotechnology in the glass industry incorporates the self-cleaning property of glass.

Fire-protective glass is another application of nanotechnology. This is achieved by using a clear intumescent layer sandwiched between glass panels (an interlayer) formed of fumed silica (SiO2) nanoparticles which turns into a rigid and opaque fire shield when heated. The electro chromic coatings are being developed that react to changes in applied voltage by using a tungsten oxide layer; thereby becoming more opaque at the touch of a button.

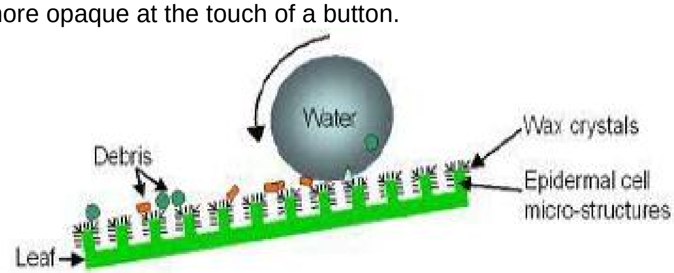

Figure 1: Self cleaning action

2.3 *Steel*

Steel is one of the most important building materials used today. The major problems of using steel however dealing with fatigue is. "Exhaustion is one of the significant issues that can lead to the structural failure of steel subject to cyclic loading," Fatigue can occur at stresses that are lower than the yield stress of the steel and leads to a shortening of the steel's life. The best way to reduce the fatigue is to add copper nanoparticles to the steel. The copper nanoparticles can help reduce the unevenness in the surface of the steel, which in turn reduces the amount of stress risers. Since the steel now has less stress risers, fatigue cracking is limited as well. Advancements in this technology through the use of nanoparticles would lead to increased safety, less need for regular inspection, and more efficient materials free from fatigue issues for construction steel cables can be strengthened using carbon nanotubes. Stronger cables reduce the life cycle costs and period of construction due to easy handling, especially in suspension bridges, as the cables are run from end to end of the span.

Research work on vanadium and molybdenum nanoparticles has shown that they improve the delayed fracture problems associated with high strength bolts. This is the result of the nanoparticles reducing the effects of hydrogen embrittlement and improving the steel microstructure through reducing the effects of the inter-granular cementite phase .Instead of *CNTs* two relatively new products that are available today are Sandvik Nanoflex (produced by Sandvik Materials Technology) and *MMFX*2 steel (produced by *MMFX* Steel Corp). Both are corrosion resistant, but have different mechanical properties and are the result of different applications of nanotechnology.

2.4 *Coating, Paints and Isolation Materials*

The coatings in corporating certain Nano particles or Nano layers have been developed for certain purpose including: protective or anti-corrosion coatings for components; self-cleaning, thermal control, energy saving, antireflection coatings for glass/windows; easy-to-clean, antibacterial coatings for work surfaces; and more durable paints and anti-graffiti coating for buildings and structures.

The coatings should have self-healing capabilities through a process of "self assembly ".Since these coatings are hydrophobic and repel water from the metal pipe and can also protect metal from salt water attack. Nanoparticle based systems can provide better adhesion and transparency .The TiO_2 coating captures and breaks down organic and inorganic air pollutants by a photo catalytic process, which leads for putting roads to good environmental use. Special coatings can also make the applied surface both hydrophobic and oleophobic at the same time. These could be used for anti-graffiti surfaces, carpets and protective clothing etc. Researchers in Mexico has successfully developed a new type of anti-graffiti paint DELETUM, by functionalising nanoparticles and polymers to form a coating repellent to water and oil at the same time, as shown in Figure 2.

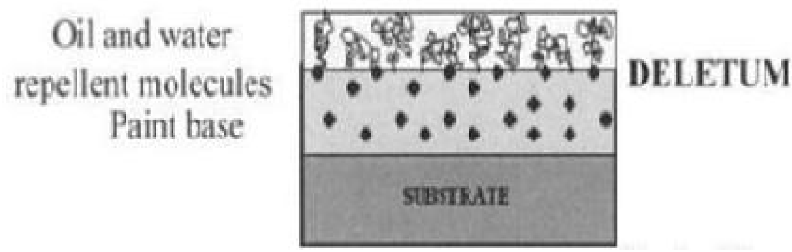

Figure 2: Stratigraphy of Deletum anti-graffiti coating

2.5 *Nanosensors*

Nanotechnology enabled sensors/devices also offer great potential for developing smart materials and structures which have ‘self-sensing’ and ‘self-actuating’ capability. 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 10-9m to 10-5 m which could be embedded into the structure during the construction process.

2.*6 Nanotechnology In Geotechnical Engineering (NRC, 2006)*

NRC highlighted that soil scientists and engineers, with their interest in the study of clay-size particles (< 0.002 mm), are among the earliest workers in the field of nanotechnology. Most of the material types and properties change with scale. At nanoscale the inter-particle interaction gains relevance. Nanomaterials possess very high specific surface activity (ratio of surface area to mass), and chemical activity which is specific surface dependent. For example, the specific surface of a 1 nm cube is about $2400m^2/g$. The maximum specific surface for bentonite clay (sodium montmorillonite) is $800m^2/g$, and about half of the constituent atoms are exposed at the surface and thus available for chemical interactions

Nanoparticles might also be engineered to act as functional nanosensors and devices that can be extensively mixed in the soil mass or used as smart tracers for in situ chemical analysis, characterization of groundwater flow, and determination of fracture connectivity, among other field applications.

3 IMPACT OF NANOTECHNOLOGY ON CONSTRUCTION

3.1 *Merits*

- Compared with conventional TiO_2, TiO_2 at the nano-scale experiences a 500% increase in surface area and a 400% decrease in opacity. Current nano-TiO_2 production levels have reached approximately 4 million metric tons at a price of approximately \$45/kg to \$50/kg vs. \$2.5/kg for conventional TiO_2.
- The CNT market worldwide is expected to grow from \$51 million in 2006 to more than \$800 million by 2011(BCC Research 2008).
- Nano-modified concrete cuts down construction schedules while reducing labour-intensive (and expensive) tasks. Also it can reduce the cost of repair and maintenance.

- The paint and coatings industry consists of approximately annual sales of $20 billion (Baer et al. 2003). Nanoalumina and titania have a four- to six-fold increase in wear resistance, with doubled toughness and bond strength (Gell 2002).
- The potential global market of nano composites is estimated at $340 billion for the next two decades (Roco and Bainbridge 2001).
- The market for fire protection systems totalled approximately $45 billion in 2004 and is expected to grow to more than $80 billion by 2010 (Helmut Kaiser Consultancy 2008)
- Self-repairing asphalt, healing and rejuvenating nanoagents for asphalt (Partl et al. 2006), and self-assembling polymers improve asphalt mix.
- Nano sensors embedded in infrastructural materials can provide, at minimum cost, fully integrated and self powered failure prediction and forecasting mechanisms for high-capital structures (e.g., reservoirs, nuclear power plants, and bridges)

3.2 *Demerits*

- Because of their small particle size, nano particles have the potential to negatively affect the respiratory and digestive tracks and the skin or eye surface [4] thus exposes workers to hazards.
- Since nanotechnology-related industries are relatively new, the type of worker who is employed in construction research and development (or even some field applications) must have an interdisciplinary background.
- New policies in the context of nanotechnology will require cooperation between various levels of government, R&D agencies, manufacturers, and other industries.
- Small production volumes and high cost remain the main barriers to the use of nanotechnology (The Royal Society 2004)
- The time for commercializing a product is long. E.g. the concrete, which can eliminate the need for reinforcing bars, is projected to be commercialized by approximately 2020.

4 ENVIRONMENT AND NENOTECHNOLOGY

The effect of various nano-materials on natural environment is hotly debated in nanotechnology and environmental researches. Various ongoing investigations have focused on the uncertainty regarding the potential effects of materials that exist on nano-scale with properties that are different than when using the material on a micro or macro scale (NNI 2003). Some work in this regard shows that the potential effects may be minimal (Tong et al. 2007). As constructed infrastructure are provided in 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 natural environment should not be negative. Typical potential problems in this regard include leaching of materials into groundwater, releasing materials into airways through the generation of dust, and exposing potentially harmful materials during construction and maintenance operations. The nanotechnology becomes a double-edged sword to the construction industry. More researches and practice efforts are needed with smart design and planning so that construction projects can be made sustainable, and therefore, save energy, reduce resource usage, and avoid damages to the environment.

5 CONCLUSIONS

Based on the short review in this paper, nanotechnology has the potential to be the key to a brand new world in the field of construction and building materials. Although replication of natural systems is one of the most promising areas of this technology, scientists are still trying to grasp their astonishing complexities. 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. Large amounts of funds and effort are being utilized to develop nanotechnology.

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