OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Study on Nano materials and Application of Nanotechnology and Its Impacts in Construction

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Abstract: *The recent researches on nanomaterials and nanotechnologies have highlighted the potential use of these materials in various fields such as medicine, construction, automobile industry, energy, telecommunications and informatics. This is due to the special characteristics of materials at the nano scale. Building materials domain can be one of the main beneficiaries of these researches, with applications that will improve the characteristics of concrete, steel, glass and insulating materials. Improving the materials resistances and the increasing of their durability will reduce environmental pollution by reducing the carbon footprint of the building. In general, the largest amount of pollutants is due to the production of various construction materials and to the energy required during their service. Moreover, nanomaterials applied to the surfaces of structural elements of the building can contribute to environmental cleaning by photocatalytic reactions. This paper examines and documents applicable nanotechnology based products that can improve the overall competitiveness of the construction. The areas of applying nanotechnology in construction will be mainly focused on: (1) lighter and stronger structural composites, (2) low maintenance coating, (3) better properties of cementitious materials, (4) reducing the thermal transfer rate of fire retardant and insulation, and (5) construction related nano-sensors.*

Keywords: *Nanomaterials; nanotechnologies; structural behavior; construction.*

I. Introduction

The new forms of today's buildings, which are proportional to mankind's modern needs, are not only due to different designs, but the application and type of building materials that are used in the construction, also has a significant effect on modern buildings' being different. People's new points of view on preserving the environment and saving energy is the outcome of this perspective that without building materials, there won't be any new products. In buildings that were built in the past two decades, both technical and aesthetic considerations were taken into account. Meanwhile, new material engineering progresses have caused technological facilities to increase and just like the aesthetic aspect of building materials, they are considered an opportunity to design. Common building materials that are used in today's constructions are bricks, stones, glass, and plaster, steel and concrete; with the main effect of natural building materials being taken quite seriously in recent years. Translucent concrete, composites, colorful refractory bricks, etc. are some of these examples.

Currently, the use of nanomaterials in construction is reduced, mainly for the following reasons: the lack of knowledge concerning the suitable nanomaterials for construction and their behavior; the lack of specific standards for design and execution of the construction elements using nanomaterials; the reduced offer of nanoproducts; the lack of detailed informations regarding the nanoproducts content; high costs; the unknows of health risks associated with nanomaterials.

In order to be able to use in the construction industry the nanomaterials at wide scale it is necessary that the researches to be conducted following the next stages: the choice of nanomaterials with potential use in construction and the study of their characteristics; the behavior study of the building elements that contain nanomaterials under various loads; the development of specific design and construction standards.

This paper examines and documents applications of nanotechnology that can improve the overall competitiveness of the construction industry. The data and information collected is from current literature and researches and focus on nanotechnology basics and applications of nanotechnology and nonmaterial in construction areas. 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.

II. Nano-Materials For Construction

2.1 Carbon-Nanotubes

Carbon nanotubes are a form of carbon having a cylindrical shape, the name coming from their nanometre diameter. They can be several millimetres in length and can have one “layer” or wall (single walled nanotube) or more than one wall (multi walled nanotube). Nanotubes are members of the fullerene structural family and exhibit extraordinary strength and unique electrical properties, being efficient thermal conductors. For example, they have five times the Young’s modulus and eight times (theoretically 100 times) the strength of steel, whilst being 1/6th the density.

Expected benefits of carbon nanotubes are: mechanical durability and crack prevention in concrete enhanced mechanical and thermal properties in ceramics and real-time structural health monitoring capacity.

2.2 Titanium Dioxide Nanoparticles (TiO_2)

The titanium dioxide nanoparticles are added to concrete to improve its properties. This white pigment is used as an excellent reflective coating or added to paints, cements and windows for its sterilizing properties. The titanium dioxid breaks down organic pollutants, volatile organic compounds and bacterial membranes through powerful photocatalytic reactions, reducing air pollutants when it’s applied to outdoor surfaces. Being hydrophilic gives self cleaning properties to surfaces to which it is applied, because the rain water is attracted to the surface and forms sheets which collect the pollutants and dirt particles previously broken down and washes them off. The resulting concrete surface has a white colour that retains its whiteness very effectively.

2.3 Silicon Dioxide Nanoparticles (SiO_2)

Nano-SiO_2 could significantly increase the compressive strength of concretes containing large fly ash volume at early age, by filling the pores between large fly ash and cement particles. Nano-silica decreases the setting time of mortar when compared with silica fume (microsilica) and reduces bleeding water and segregation by the improvement of the cohesiveness.

2.4 Zinc Oxide Nanoparticles (ZnO)

Zinc oxide is a unique material that exhibits semiconducting and piezoelectric dual properties. It is added into various materials and products, including plastics, ceramics, glass, cement, rubber, paints, adhesive, sealants, pigments, fire retardants. Used for concrete manufacturing, ZnO improves the processing time and the resistance of concrete against water.

2.5 Silver Nanoparticles (Ag)

The nanosilver will affect, in contact with bacteria, viruses and fungi, the cellular metabolism and inhibit cells growth. The nanosilver inhibits multiplication and growth of bacteria and fungi, which causes infection, odour, itchiness and sores. The core technology of nanosilver is the ability to produce particles as small as possible and to distribute these particles very uniformly. When the nanoparticles are coated on the surface of any material, the surface area is increasing several million times than the normal silver foil.

2.6 Aluminum Oxide Nanoparticles (Al_2O_3)

Alumina (Al_2O_3) component reacts with calcium hydroxide produced from the hydration of calcium silicates. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. The addition of nano-Al_2O_3 of high purity improves the characteristics of concretes, in terms of higher split tensile and flexural strength. The cement could be advantageously replaced in the concrete mixture with nano-Al_2O_3 particles up to maximum limit of 2.0% with average particle sizes of 15 nm, the optimal level of nano-Al_2O_3 particles content being achieved with 1.0% replacement.

2.7 Zirconium Oxide Nanoparticles (ZrO_2)

Zirconium oxide (or Zirconia) nanopowder or nanoparticles are white high surface area particles with typical dimensions of 5…100 nanometers and specific surface area in the 25…50 m2/g range. Nano zirconium shows good aesthetics (translucency), superior physical resistance (hardness, flexibility, and durability), and chemical resistance (practically inert) and is a very good insulator.

2.8 Wolfram (Tungsten) Oxide Nanoparticles (WO_3)

In recent years, tungsten trioxide has been employed in the production of electro-chromic windows, or smart windows. These windows are electrically switchable glass that change light transmission properties with an applied voltage. This allows the user to tint their windows, changing the amount of heat or light passing through.

III. 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 characteristics can, again, significantly fix current construction problems, and may change the requirement and organization of construction process.
These include products that are for:

- Lighter and stronger structural composites
- 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

The abbreviated list is not an exhaustive list of applications of nanotechnology in construction. Some of these applications are examined in detail below.

3.1 Nanotechnology for concrete

"Concrete is one of the most common and frequently used building materials. Annually, about a ton of concrete is produced for every individual in the world. Consumption of energy and the carbon dioxide which is produced during the production processes of cement, concrete and wastes are the most important environmental issues related to concrete production and use. Nanotechnology has been a great help to researchers in the field of concrete industry. In fact, it has led to the production of new cements, concretes, additives and nanocomposites. According to conducted studies, adding nanoparticles would improve the durability of concrete through physical and chemical interactions like concrete pore fillers.

By adding fibers that are nanometers to micrometers long and are made of carbon, steel or polymers, researchers have reinforced concrete. Experimental Literatures have shown that after 28 days, the compressive strength of these concretes is doubled compared with ordinary concretes that are traditionally reinforced. Also, the developments of such materials guide building constructors to reduce their cement consumption by 50 percent compared with normal conditions". To improve concrete properties, two nanotechnologies are introduced here:

3.1.1 Nano-silica and Self-healing Concretes

"In the concrete industry, silica is one of the best known substances that play an important role in a concrete's cohesion and pore-filling properties with a high degree performance. To get a better result, nanoconcrete is included in the concrete-cement mixture which besides being more cohesive, it increases its adhesion and integrity as well". Adding nano-silica (SiO_2) to concrete can improve its mechanical properties by creating more compressed microparticles and nanostructures. In fact, nano-silica increases the durability of concrete by reducing the calcium level in the water that is needed for soaking the cement and also, by decreasing water penetration. Moreover, it helps adding more fly ashes to the concrete without affecting its strength and curing speed which in turn, causes the durability and strength of concrete to increase and the cement consumption to reduce.

"Self-healing concrete is another achievement of nanotechnology. There are researches that are still being conducted on this type of concrete. When this concrete cracks, microcapsules that are placed in it are broken and release the healing agent into the damaged area through the capillary action. The said agent contacts the catalyzer embedded inside the concrete and releases a polymer, which fills the crack's surface.
In test cracks, self-healing composites regained their initial strength up to 75%. Usually, they can double or triple the life of structural compounds compared with normal conditions. This concrete can be used for repairing micro cracks in bridge and dock columns".

3.1.2 Carbon Nanotubes

"One of the greatest discoveries relevant to nanotechnology is nanotubes. These tubes are plates made of carbon atoms that move inside a roller-like compartment and they seem like wire screens that are coated on one side. Carbon nanotubes are hollow and usually made of carbon sources such as graphite. Due to characteristics such as their vast specific surface area, great strength of up to several times more than steel and also, exceptional electric and electronic properties, they have applications like being a catalyst and a mechanical booster of polymers and composites and are used in manufacturing electronic parts. They are ten times stronger than steel, while weighing one sixth of its weight". In the concrete industry, these nanomaterials can be used as fibers for flattening and modifying the mechanical function of concrete. In this field, carbon nanotubes can play an important role as multi-purpose building materials of high degree performances compared with steel and aluminum. Stress and compressive resistances of the said nanotubes are much higher compared with those of other building materials.

3.2 Nanotechnology for Steel

The addition of copper nanoparticles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking, leading to increased safety, less need for monitoring and more efficient materials use in construction subjected to fatigue issues. Vanadium and molybdenum nanoparticles improve the delayed fracture problems associated with high strength bolts, reducing the effects of hydrogen embrittlement and improving the steel micro-structure.

The addition of nanoparticles of magnesium and calcium leads to an increase in weld toughness. The carbon nanotubes have little application as an addition to steel because of their inherent slipperiness, due to the graphitic nature, making them difficult to bind to the bulk material. Also, the high temperatures involved in the steel elements production process enhances the vibration of carbon atoms significantly, leading to bond breaking and deffects in the nanotubes structure.

3.3 Nanotechnology for Coating

The coatings incorporating certain nanoparticles or nanolalyers have been developed for certain purpose. It is one of the major applications of nanotechnology in construction. For example, TiO2 is used to coat glazing because of its sterilizing and anti-fouling properties. The TiO2 will break down and disintegrate organic dirt through powerful catalytic reaction. 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, and anti-reflection coating.

3.4 Nanotechnology for Wood

Wood is composed of nanotubes or “nanofibrils”. Lignocellulosic surfaces at the nanoscale could open new opportunities for such things as selfsterilizing surfaces, internal self-repair, and electronic lignocellulosic devices, providing feedback for product performance and environmental conditions during service. Highly water repellent coatings incorporating silica and alumina nanoparticles and hydrophobic polymers are proper to be used for wood.

3.5 Nanotechnology for Painting

Nanotechnology is applied to paints in order to assure the corrosion protection under insulation since it is hydrophobic and repels water from the metal pipe and can also protect metal from salt water attack.

3.6 Nanotechnology for 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 (SiO_2) nanoparticles which turns into a rigid and opaque fire shield when heated. The electrochromic 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. Because of the hydrophobic properties of TiO_2, it can be applied in antifogging coatings or in self-cleaning windows. Nano-TiO2 coatings can also be applied to building exteriors to prevent sticking of pollutants, and thus reduce a facility’s maintenance costs.

3.7 Nanosensors

Nanotechnology enabled sensors/devices which exhibit 'self-sensing' and 'self-actuating' capability also offer great potential for developing smart materials and structures. The device used for air bags in cars is such an example. Nano and Micro electrical mechanical systems (NEMS & MEMS) sensors range from 10^{-9} m to 10^{-5} m which could be embedded into the structure during the construction process. They can 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. 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. Also it can provide an early indication before a failure of the structure occurs. Thus the sensors are able to work as self-health monitoring system.

Cyrano Sciences has developed electronic noses based on an array of different polymer nanometre-thin film sensors. Siemens and Yorkshire Water are developing autonomous, disposable chips with built-in chemical sensors to monitor water quality and send pollution alerts by radio.

3.8 Nanotechnology for Fire-protection

Fire resistance of steel structures is often provided by a coating of spray on cementitious process which is no more 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 paradigm in this area of application. This is achieved by the mixing of carbon nanotubes (CNT's) with the cementious material to fabricate fibre composites that can inherit some of the outstanding properties of the nanotubes such as strength. Polypropylene fibres are also being considered as a method of increasing fire resistance and this is a cheaper option than conventional insulation. CNTs can also be used to produce protective clothing materials because of their flame retardant property.

3.9 Nanotechnology for green building

Nanotechnology, the manipulation of matter at the molecular scale, is bringing new materials and new possibilities to industries as diverse as electronics, medicine, energy and aeronautics. Our ability to design new materials from the bottom up is impacting the building industry as well. New materials and products based on nanotechnology can be found in building insulation, coatings, and solar technologies. Work now underway in nanotech labs will soon result in new products for lighting, structures, and energy. In the building industry, nanotechnology has already brought to market self-cleaning windows, smog-eating concrete, and many other advances. But these advances and currently available products are minor compared to those incubating in the world's nanotech labs today. There, work is underway on illuminating walls that change colour with the flip of a switch, nanocomposites as thin as glass yet capable of supporting entire buildings, and photosynthetic surfaces making any building facade a source of free energy.

IV. Impacts in Construction

4.1 Merits

1) 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.
2) The CNT market worldwide is expected to grow from $51 million in 2006 to more than $800 million by 2011.
3) Nano-modified concrete cuts down construction schedules while reducing labour-intensive (and expensive) tasks. Also it can reduce the cost of repair and maintenance.
4) The paint and coatings industry consists of approximately annual sales of $20 billion. Nano-alumina and titania have a four- to six-fold increase in wear resistance, with doubled toughness and bond strength.
5) The potential global market of nanocomposites is estimated at $340 billion for the next two decades.
6) The market for fire protection systems totaled approximately $45 billion in 2004 and is expected to grow to more than $80 billion by 2010.
7) Self-repairing asphalt, healing and rejuvenating nanoagents for asphalt, and self-assembling polymers improve asphalt mix.
8) 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.

4.2 Demerits

1) Nano particles being very small in size have the potential to negatively affect the respiratory and digestive tracks and the skin or eye surface thus exposes workers to hazards.
2) 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.
3) New policies in the context of nanotechnology will require cooperation between various levels of government, R&D agencies, manufacturers, and other industries.
4) Small production volumes and high cost remain the main barriers to the use of nanotechnology.
5) 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.

V. Future Challenge and Conclusion

Nano materials and nanotechnologies have attracted considerable scientific interest due to the new potential uses of particles in nanometer scale and, consequently, large amount of funds and effort have being utilized. Even though construction materials may constitute only a small part of this overall effort, it could pay enormous rewards in the areas of technological breakthroughs and economic benefits.

Using nanotechnology helps less energy consumption in a building, which is considered one of the main concerns of the world today. Nanotechnology reduces mankind's need to rare materials and by decreasing the level of pollutants in the process of producing building materials, eventually reduces environmental pollution. It is hoped that by providing necessary conditions, using nanotechnology in the construction industry would lead to creating safer buildings of higher qualities that are cost effective.

Therefore, it is necessary and urgent to regulate the construction and its related performance to sustainable manners. 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. It is necessary to establish a system to identify the environmentally friendly and sustainable of construction nanomaterials and to avoid the use of harmful materials in the future.

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