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NANOMATERIALS AND NANOTECHNOLOGIES FOR CIVIL ENGINEERING

BY

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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 are due to the production of various construction materials and to the energy required during their service.The use of nanomaterials in the composition of some materials, such as cement, will result in significant reductions of CO_2 pollution and the use of performance thermal insulations will result in efficient use of energy for air conditioning. Moreover, nanomaterials applied to the surfaces of structural elements of the building can contribute to environmental cleaning by photocatalytic reactions.

Key words: nanomaterials; nanotechnologies; structural behavior; construction.

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1. Introduction

Nanomaterials can be defined as those physical substances with at least one dimension between 1…150 nm (1 nm = 10^{-9} m). The nanomaterials properties can be very different from the properties of the same materials at micro (10^{-6} m) or macro scale ($10^{-6}…10^{-3}$ m).

The nanoscience representss the study of phenomena and the manipulation of materials at nanoscale and is an extension of common sciences into the nanoscale.

The nanotechnologies can be defined as the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanoscale. Nanotechnology requires advanced imaging techniques for studying and improving the material behavior and for designing and producing very fine powders, liquids or solids of materials with particle size between 1 and 100 nm, known as *nanoparticles* (Gogotsi, 2006).

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 is part of the first stage of research and represents a synthesis of nanomaterials proper to be used in construction.

2. Nanomaterials for Construction

Because the size of the particles is a critical factor, the material properties significant differ at the nanoscale from that at larger scales. Physical phenomena begin to occur differently below the boundary limit: gravity becomes unimportant, electrostatic forces and quantum effects start to prevail. In the same time, the proportion of atoms on the surface increases relative to those inside, creating so-called “nano-effect”. All these nano-properties actually affect the materials behavior at macro-scale and, from this point, the power of nanotechnology is emphasized: if the elements are proper manipulated at the nanoscale, the macro-properties are affected and new materials and processes can be developed (Ge & Gao, 2008).

In what follows the most important nanomaterials with potential use in construction are presented.

2.1. The 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) (Lu *et al*., 2010).

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 (Mann, 2006).

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 (Mann, 2006).

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 (Sadrmomtazi & Barzegar, 2010).

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 (Broekhuizen & Broekhuizen, 2009).

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 (www.nanosilver.com.my).

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 (Nazari *et al*., 2010).

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 m^2/g range. Nano zirconium shows good aesthetics (translucency), superior physical resistance (hardness, flexibility, durability), 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 electrochromic 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.

3. Nanotechnologies for Construction

Nanotechnology can generate products with many unique characteristics that can improve the current construction materials: lighter and stronger structural composites, low maintenance coatings, better cementitious materials, lower thermal transfer rate of fire retardant and insulation, better sound absorption of acoustic absorbers and better reflectivity of glass (Lee *et al*., 2010).

3.1. Nanotechnologies for Concrete

Concrete is a macro-material strongly influenced by its nano-properties. The addition of nano-silica (SiO_2) to cement based materials can control the degradation of the calcium-silicatehydrate reaction caused by calcium leaching in water, blocking water penetration and leading to improvements in durability (Mann, 2006).

Nano-sensors have a great potential to be used in concrete structures for quality control and durability monitoring. (to measure concrete density and viscosity, to monitor concrete curing and to measure shrinkage or temperature, moisture, chlorine concentration, pH, carbon dioxide, stresses, reinforcement corrosion or vibration).

Carbon nanotubes increase the compressive strength of cement mortar specimens and change their electrical properties which can be used for health monitoring and damage detection.

The addition of small amounts (1%) of carbon nanotubes can improve the mechanical properties of mixture samples of portland cement and water. Oxidized multi-walled nanotubes show the best improvements both in compressive strength and flexural strength compared to the reference samples.

3.2. Nanotechnologies 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 (Mann, 2006).

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 (Mann, 2006). 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. Nanotechnologies for Wood

Wood is composed of nanotubes or “nanofibrils”. Lignocellulosic surfaces at the nanoscale could open new opportunities for such things as self-sterilizing surfaces, internal self-repair, and electronic lignocellulosic devices, providing feedback for product performance and environmental conditions during service (Mann, 2006).

Highly water repellent coatings incorporating silica and alumina nanoparticles and hydrophobic polymers are proper to be used for wood.

3.4. Nanotechnologies for Glass

The use of TiO_2 nanoparticles to glasses leads to so-called *self cleaning technology*. Due to the nanoparticles photocatalytic reactions, the organic pollutants, volatile organic compounds and bacterial membranes are decomposed. As well, TiO_2 being hydrophilic, his attraction to water forms drops which then wash off the dirt particles decomposed in the previous process.

Fire-protective glass is obtained using fumed silica (SiO_2) nanoparticles as a clear interlayer sandwiched between two glass panels which turns into a rigid and opaque fire shield when is heated.

3.5. Nanotechnologies for Coatings and Paitings

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. Others applications refer to coatings that have self healing capabilities through a process of “self-assembly”. In addition to the self-cleaning coatings mentioned above for glazing, the remarkable properties of TiO_2 nanoparticles are put to use as a coating material on roadways in tests around the world (Mann, 2006).

3.6. Nanotechnologies for Thermal Insulation

Micro- and nanoporous aerogel materials are appropiate for being core materials of vacuum insulation panels but they are sensitive to moisture. As a possible remedy it was produced an ultra-thin wall insulation which uses a hydrophobic nanoporous aerogel structure.

Another application of aerogels is silica based products for transparent insulation, which leads to the possibility of super-insulating windows.

Micro- or nanoelectomechanical systems offer the possibility of monitoring and controlling the internal environment of buildings and this could lead to energy savings.

3.7. Nanotechnologies for Fire Protection

Fire resistance of steel structures is often provided by a coating produced by a spray-on cementitious process. Nano-cement (made of nano-sized particles) has the potential to create a tough, durable, high temperature coatings. This is achieved by the mixing of carbon nanotubes with the cementious material to fabricate fibre composites that can inherit some of the outstanding properties of the nanotubes.

3.8. Nanotechnologies for Structural Monitoring

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. Nanosensor ranges from 10^{-9} to 10^{-5} m. These sensors could be embedded into the structure during the construction process and could monitor internal stresses, cracks and other physical forces in the structures during the structures' life (Lee *et al.*, 2010).

4. Conclusions

Nanomaterials 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.

Although today the total market share of nano products for construction is small and deemed to be applied in niche markets, this share is expected to grow in the near future, and nanoparticles to play an important role as a basis for the design, development and production of materials construction industry.

Following the synthesis achieved in this paper, it can be concluded that the use of nanomaterials in construction is viable in four major directions of development: structural concrete; real time structural monitoring; coatings and paintings; thermal insulations.

The first two directions of development are of major interest. Further, in the research process will be studied: the possibility of replacement of steel reinforcements in the reinforced concrete with carbon nanotubes able to take the tensile stresses; the possibility of increasing the durability of concrete using nanomaterials; the development of real time monitoring systems for structural elements using nanomaterials embedded in concrete in order to obtain safer buildings.

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REFERENCES

Broekhuizen F.A, Broekhuizen J.C., *Nanotehnologia în industria europeană a construcțiilor – Stadiul actual al tehnologiei* (transl. from English). 2009, 7-30, www.efbww.org.

Ge Z., Gao Z., *Applications of Nanotechnology and Nanomaterials in Construction*. First Internat. Conf. on Constr. In Develop. Countries (ICCIDC–I): "Advancing and Integrating Construction Education, Research & Practice", Karachi, Pakistan, August 2008, 235-240.

Gogotsi Y., *Nanomaterials Handbook*. Taylor & Francis Group, LLC, 2006, 1-2.

Lee J., Mahendra S., Alvarez P., *Nanomaterials in the Construction Industry: A Review of their Applications and Environmental Health and Safety Considerations*. ACS Nano, **4**, *7*, 3580-3590 (2010).

Mann S., *Nanotechnology and Construction*. European Nanotechnology Gateway - Nanoforum Report, Institute of Nanotechnology, November 2006, 2-10

Nazari A., Shadi R., Sharin R., Shamekhi S.F., Khademno A., *Al_2O_3 Nanoparticles in Concrete*. J. of Amer. Sci., **6**, *4*, 94-97 (2010).

Sadrmomtazi A., Barzegar A., *Assessment of the Effect of Nano-SiO_2 on Physical and Mechanical Properties of Self-Compacting Concrete Containing Rice Husk Ash*. Sec. Internat. Conf. on Sustain. Constr. Mater. a. Technol., U.P.M., Ancona, Italy, June 2010, 3-8.

* * * *What is Nanotechnology and Nanosilver. Efficacy of Nanosilver*. www.nano-silver.com.my

NANOMATERIALE ŞI NANOTEHNOLOGII ÎN CONSTRUCȚII

(Rezumat)

Cercetările efectuate în ultimii ani în domeniul nanomaterialelor şi nanotehnologiilor au pus în evidență potențialul de utilizare al acestor materiale în domenii diverse, cum ar fi: medicina, industria construcțiilor, industria auto, sectorul

energetic, telecomunicațiile şi domeniul informaticii. Acest fapt se datorează caracteristicilor deosebite ale materialelor la scară nano. Domeniul materialelor de construcții este unul dintre principalii beneficiari ai acestor cercetări, ale căror aplicații vor conduce la îmbunătățirea caracteristicilor betonului, oțelului, sticlei, materialelor fono- şi termoizolante. Îmbunătățirea rezistențelor materialelor şi creşterea durabilității acestora vor conduce la reducerea poluării mediului înconjurător, prin reducerea amprentei de carbon a construcțiilor. În general, cea mai mare cantitate de agenți poluanți se datorează procesului de producție al diverselor materiale de construcție şi consumului de energie pe durata exploatării acestora. Utilizarea nanomaterialelor în componența unor materiale, cum ar fi cimentul, va conduce la reduceri semnificative ale poluării cu CO_2, iar utilizarea unor termoizolații performante va avea ca efect economisirea de energie pentru climatizare. Mai mult, nanomateriale aplicate pe suprafețele elementelor de construcție pot contribui la depoluarea mediului înconjurător prin reacțiile fotocatalitice pe care le produc.