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Applications of Nanocomposites in Architecture and Construction.

Aplicaciones de Nanocompuestos en Arquitectura y Construcción.

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Silverio Hernández Moreno[1]
Sara Cristina Solache de la Torre[2]

Abstract

This paper is a review article that has as objective to offer an overview of the use and application of nanocomposites in architecture and construction industries on the basis of a review of scientific literature from the architect's standpoint. The applications divide and classify mainly according to the use of nanomaterials to improve their properties and functioning from a number of categories of construction materials such as: improvement of strengths of Portland-based concrete adding nanomaterials: improvement of reinforcing steel's corrosion and deterioration resistance adding nanomaterials; use of nanocomposites to repel dampness and dust, fingerprints and bacteria in construction components; thermal insulation and UV protection; in new-generation photovoltaic cells and panels; high-quality, long-lasting waterproofing materials and sealants; in electronic parts and components of telecommunication and illumination; in the production of water filters, purifiers and treatment equipment. It is concluded that improvement to such materials by means of nanocomposites will depend on a number of situations such as: design, amounts, characterization and assessment of construction materials in relation to components and construction systems; weather and degradation conditions that affect materials; conditions of use and maintenance that affect the materials, procedures and quality in the production and construction of the components and materials.

Key wordS

Nanocomposites, Nanodesign, Nanotechnology.

Resumen

Artículo de revisión que tiene como objetivo presentar un panorama del uso de nanocompuestos dentro de la arquitectura y construcción con base en revisión de literatura científica y desde el punto de vista del arquitecto. Las aplicaciones se clasifican de acuerdo al uso del nanomaterial para mejorar sus propiedades y funcionamiento en un número determinado de categorías de materiales de construcción, tales como: mejoramiento de resistencias mecánicas del concreto de base de cemento Portland; mejoramiento de las resistencias a la corrosión y deterioro del acero de refuerzo; repelencia al polvo, humedad, grasa y bacterias; aislamiento térmico y protección de rayos UV; en células y paneles fotovoltaicos de nueva generación; impermeabilizantes y selladores de alta calidad; en partes y componentes electrónicos de telecomunicaciones y de iluminación; en equipos de purificación, tratamiento y filtros de agua. Se concluye que el mejoramiento de cada uno de los materiales a través de nanocompuestos dependerá de cada situación respecto a: su diseño, su dosificación, su caracterización y evaluación del material respecto al componente constructivo del cual forme parte, del clima y de las condiciones de degradación, del uso y mantenimiento así como de la calidad de mano de obra en la construcción o instalación de los componentes y de los materiales.

Palabras clave

Nanocompuestos, Nanodiseño, Nanotecnología

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1.Introduction

Nano-products as successful nowadays as graphene, fullerene, nano-silica, nano-titanium oxide, nano-alumina, carbon nanotubes, etc., made of various nanomaterials (nanomaterial understood as substances at nano-metric scale that compose some structured component) and with numberless applications that can solve problems related to the correlated variables density-strength, durability-esthetics, in addition to repellence to dampness, dust and bacteria; to improve systems of energy storage, insulating glass, water purification, electric conductors and semiconductors and other numerous applications in materials and components mainly utilized in building structures such as roofs, mezzanines, walls, columns and other parts such as latticework, windowpanes, finishes and facades are of great interest for architects, engineers, builders and real-estate developers to include them in the design and construction of their projects.

Successful cases are mentioned, in fact, through this document with registered trademarks which have already been tested and which, in turn, show the advantages over traditional materials for the same purposes in construction.

In architecture and construction industry, nanotechnology applications range from the improvement of the traditional mechanical properties of concrete, anti-corrosive protection for reinforcing steel, of materials and products such as paints, sealants and glass (to make them repellent to bacteria and other noxious biological agents) to the improvement of thermal and pyro-resistant properties of materials, to name a few.

Many of the previous instances are nanocomposite materials; this is, they are the combination of traditional materials such as ceramics, metals and polymers with nanomaterials (e.g., nano-silica, nanotubes, nanofibers, etc.) in different phases: continuous, for example nano-silica in a binding matrix (the case of concretes and mortars based on Portland cement) and disperse (with aggregates such as nanofibers, nanotubes and other reinforcements by precipitation) which added would yield nanocomposite materials to improve many of the physical and chemical properties that composite materials normally have.

It is very important to point out, that at present, nano materials are still in the stage of experimentation and research, so there are no exact points to make comparisons, since their applications are very recent and also the environmental consequences in the management of their wastes, very little information has been generated that is not convincing for immediate or future evaluation or/ and comparatives.

Nanoparticles are materials at nanometric scale that range from 1 to 100 nm (Fahlman, 2011) and which can be nanopowders, nanowires, nanotubes, nanohorns, nanocrystals, nanopores, nanofilms, nanomembranes, nanofibers, etc.

As for the origin and evolution of nanotechnology, before 1700 the use of nanoparticles was limited, for instance, to produce high-quality glass with various colorations for stained glass; in ceramics and tile production (Larramendy and Soloneski, 2016).

The success of the study and application of nanomaterials is that at nanometric scales materials improve their physical and chemical characteristics such as thermal conductivity, mechanical strengths, electric conductivity, magnetic behavior, catalytic activity, melting point, optical and fluorescent absorption, etc., this way, at macro level or larger scales such characteristics and properties can improve substantially because at small scales, when defects such as pores, cracks and fissures are detected they are easy to control and manipulate with better detail (Kumar and Kumbhat, 2016). By and large, the unique characteristics of nanomaterials are attributed to their size, quantum effects, enormous surface area and self-assembling properties.

The main objective of improving composite materials using nanomaterials is, in the first place, to reduce the high costs of construction and maintenance of structures and other components of buildings (as covers and facades), which because of their heavy weight and low durability cause problems over their service life; secondly, accelerate construction times securing the performance desired for the project by means of the proposal of design and innovation of ultralight construction systems, easy to build and assemble, economic, durable, ecological and super resistant. And as previously mentioned, it would be to improve the physical and chemical properties and characteristics of materials in various uses.

Separately, a part of the problem in the use and application of nanomaterials in construction industry is that they are still undergoing adaption, research and development stages owing to commercial reasons and frequently due to the perception of the high cost of nano-technological products and how they are implemented in construction processes (Zhu et al., 2004). By contrast, in chemical, automotive, biomedical and electronic industries, nanotechnology is well accepted mainly because of the volumes required, which compared with construction are much lower and the investment is more profitable, as with small amounts large productions are achieved (Zhu et al., 2004).

2.Main nanocomposites used in architecture and construction industries

There is a number of nanomaterials and nano-products that can be applied to various construction materials in view of improving their properties, both physical and chemical. The main applications are listed below:

- Improvement of the strengths of concrete made with Portland cement added with nanomaterials
- Improvement of reinforcing steel regarding corrosion and deterioration adding nanomaterials
- Use of nanocomposites to repel dampness, dust, fingerprints and bacteria in construction components
- Thermal insulation and UV protection
- In new-generation photovoltaic cells and panels
- In waterproofing materials, paints, glues and sealants for high quality and durability
- In telecommunication and illumination electronic parts and components
- To produce water filters, purifiers and treatment systems

2.1 Improvement of strengths of concrete produced with Portland cement added with nanomaterials

Portland-cement-based concrete is a composite that consists of agglutinant (cement) and aggregates (sand, gravel and water), so it can be improved adding nanomaterials such as nano-silica, nanotubes or nanofibers to produce a better final product with improved mechanical strengths and durability conditions.

The key point to improve concrete is on the cementing base, which is the one that agglutinates the other materials such as coarse aggregates and continuous reinforcing (rebars) or disperse reinforcing (such as short fibers of various materials). Therefore, the cementing base or binding matrix is where there is the most interest to improve the properties of concrete such as mechanical properties, hydration phases, cohesion aspects, interfaces of the cementing base and degradation mechanisms (Sanchez and Sobolev, 2010).

The formation of concrete takes place over a number of stages and scales, from an amorphous phase at nanometric level of the cementing base (hydration of calcium silicate with molecular assembly) to a crystalline phase with interaction of particles at micrometric level and the effects of working stress at macrometric level (Sanchez F and Zhang, 2009). This indicates that Portland-based concrete is a nanocomposite itself, due to the interaction of cement with water.

If nanomaterials, e.g., silica nanoparticles, nano-alumina, nano-titanium oxide, nano-iron oxides, nano-clays or carbon nanotubes, are added to concrete mixes (Bjornstrom et al., 2004; Qing et al., 2008; Li et al., 2006; Li Z. et al., 2006; Srivastava et al., 2003), then concrete would be reinforced to produce more resistant nanocomposites with better mechanical properties that can be quantitatively measured through mechanical strength tests in the laboratory. These tests would yield better products with better properties that might even be innovative among the already existing.

Albeit, how and how much could strengths in Portland-cement mortars and concretes improve adding various sorts of nanoparticles?

Recent studies indicate, for example in compression tests assessed at different mortar ages (up to 56 days), that strengths can be increased optimizing the dosage of the mix adding nano-silica (see nano-SiO2 properties in table 1) within a range from 3 to 10% of the cement’s weight, this way compression strengths increase according to the dosage of nano-SiO2 duly dispersed in the mix up to 15% more to add 10% of nano-SiO2 on the

28th day; moreover, it accelerates the hydration process because of the improvement of the microstructure of the cementing base and greatly reduces attacks to concrete by sulfates, which prolongs the service life of this sort of materials (Ltifi et al., 2011; Saloma et al., 2015).

Similar studies with nano-SiO2 added to Portland-cement mortars, indicate an increase in compression strength at 28 days from 28.9 MPa (with no nano-SiO2) to 36.4 MPa with 10% of nano-SiO2; 31.8 MPa, adding 15% of silica fume; 36.4 MPa with 3% of nano-ferrite (nano-Fe2O3) (Li et al., 2004; Sanchez and Sobolev, 2010).

Studies that refer to the use of nano-SiO2 in high-resistance Portland-cement concretes show that compression strengths increase up to 18%, while flexion up to 4% at the age of 90 days adding 0.75% of nano-SiO2 as optimal dosage; this is to say, 1.15 kg of nano-SiO2 per 50 kg of cement (Mohamed, 2016). The study also indicated that if this optimal proportion (0.75%) is exceeded results are frequently negative.

Table 1. Average properties of nano-silica (nano-SiO2)

Average particle size (nm)	Specific surface area (m^2/g)	Density (g/cm^3)	Silica content (%)
9	300	1,218	99,9

Source: (Ltifi et al., 2011).

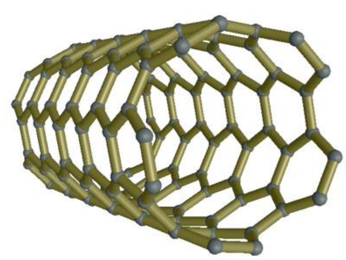
Separately, carbon nanotubes (CNT) are flexible tubular (cylindrical) structures capable of sustaining large deformations, with a diameter that varies from 1 to 40 nm and a length between 5 and 15 microns (µm), however these measures can widely vary (Kharissova and Torres Martínez, 2016). Graphene (an allotropic form of carbon) nanotubes are considered the most resistant materials in the world and can be added to cement mixes with an optimal dosage from 0.05 to 0.5 % of the cement's weight, which considerably increases strengths in pastes, mortars and concretes made with Portland cement (Kharissova and Torres Martínez, 2016). There are nanotubes of various materials such as silica or boron nitride, but the term is generally applied to carbon nanotubes, which are more versatile and the most utilized for these purposes.

Nanotubes, even deformed or bent, do not break, unlike carbon fibers or of other materials, due to their allotropic nanostructure. The average Young's module of CNT is 1000 GPa.

Carbon nanotubes have mechanical, electrical, optical, thermal, biomedical properties, and in virtue of them and in combination with crystal nanoparticles, carbon nanotubes can greatly help concrete decrease the micro-fissures and cracks that appear during setting and curing, thus improving its mechanical properties, mainly tension strength.

Using chemical vapor deposition and adding carbon nanotubes with external and internal diameters of <8 nm and 2-5 nm, respectively, and <10 nm in length in Portland-cement mortars with a ratio of 0.40 water/cement and 0.5% of the cement content at 28 days, uniformly dispersed in the mix, compression strength increased from 28.9 MPa (without reinforcement) to 54.3 MPa, while flexion strength increased from 6.0 to 8.23 MPa (Šmilauer et al., 2012; Kharissova and Torres-Martínez, 2016).

Figure 1. Carbon nanotube section designed with a graphene mesh



Source: author's own elaboration using Ninithi® modelling Software.

There are reports and studies on Portland-cement concretes that define dosages of only 0.5% of carbon nanotubes per cement weight; this is to say, 600 to 900 grams per one metric ton of normal concrete mixes with densities of 2400 kg/ m^3 to reach strengths of up to 23.3% more under compression and up to 13.6% more in flexion at 28 days (Eden Energy®, 2014).

Other similar studies verify, for example, that in Portland-cement-based concretes, with normal strengths of 38.22 N/mm^2, the addition of 0.015% of multiwall carbon nanotubes (MWCNT) in relation to the cement's weight produces a compression strength of 41.48 N/mm^2 at 28 days; the addition of 0.030% increases compression strength to 45.18 N/mm^2; and by adding 0.045 %, it increases to 49.18 N/mm^2, i.e., a 26.69-percent increment.

Considering better results are obtained with MWCNT, it is because these are more reinforced and include in their nanostructures multiple layers or meshes of graphene and not only a layer as it is the case of normal nanotubes.

2.2 Improvement of reinforcing steel regarding corrosion and deterioration adding nanomaterials

Corrosion in metals and specifically in reinforcing steel in construction industry is the cause of one of the greatest losses in global economy. To prevent this, there are numerous products and materials in the industry's market with varying results depending on their quality. Nanostructured materials have produced better results in corrosion and deterioration issues in structures and construction components because every-day there appear better nano-products that compete with the traditional ones. Many traditional techniques such as chrome plating, for example, are known to be harmful to public health, for example DNA degeneration or some types of cancer, therefore there should be alternatives to solve these problems, either public health, degradation and deterioration of the materials and construction components.

By and large, there is a number of composites such as alloys, ceramics and polymers that are utilized to prevent corrosion in construction steel. In like manner, nanotechnological materials advance in this respect. Nanocomposites of diverse nature (such as magnesium nanoparticles) are also successfully used to prevent corrosion in metals, among them steel for construction industry.

For example, graphene can be successfully utilized by means of galvanization as a protective coat in steel (Krishnamurthy et al., 2013) and likewise, nanostructured titanium oxide (TiO_2) has shown anticorrosive resistance over the average (Zaki and Aleem, 2009). Other study demonstrated that using nanoparticles such as nano-silica (Si_2O), powder nano-zinc (Zn) and nano-ferrite ($Fe_2 O_3$) greatly increases anticorrosion, as much or more than the properties of epoxy (Shi et al., 2009). Likewise, this sort of nanoparticles prevent the penetration of chlorides much better than normal epoxy resins.

The study by Hammer et al. (2012) mentions nanocomposites composed of hybrid materials (organic and inorganic) reinforced with carbon nanotubes can also inhibit corrosion as excellent steel protectors. Likewise, nano-porous titanium oxide can also greatly inhibit corrosion and be used as intermediate layer in several coatings for metals (Lamaka et al., 2007).

Studies on silane films in the use of anticorrosive materials have demonstrated that if silane (inorganic compound of SiH_4) is modified with cerium oxide nanoparticles (CeO_2), it noticeably improves its anticorrosive properties (Montemora et al., 2009).

Nano-containers assembled layer by layer, of the inorganic kind such as phosphates, vanadates, borates, cerium and molybdenum, and organic such as phenyl phosphonic acid, mercaptobenzothiazole, and triazole are some inhibitors of corrosion that may substitute common chrome plating efficaciously (Shchukin et al., 2006).

Studies on nanocomposite materials of polymers and clays using montmorillonite (MMT), which is clay with several silicate layers in combination with various polymers, has demonstrated to have great potential to be applied as a coating for metals, this way it has also demonstrated excellent anticorrosive properties (Wei-I et al., 2011).

There are many more studies, similar to those referred above, which contain information on a wide variety of nanomaterials useful against corrosion, and which are still under study and research.

For the case of reinforcing steel protection against corrosion, there are some nanocomposites commercially available, namely:

- *Super Hard Steel (SHS) Alloy Thermal Spray®*
- *LMGI high concentration oil soluble magnesium additives; Liquid Minerals Group, Inc.* ® based on magnesium nanoparticles
- *Pro-Seal 34®; Proseal products, Inc*. based on polycarbonate nanotechnologies
- *DuraSeal Nanocoatings®*
- Aluminum and copper nano-alloys as anticorrosive protection for metals
- Ferrite nanoparticles in concrete to protect reinforcing steel from sulfates, chlorides, and other corrosive agents

These are a few nanomaterial products that help preventing corrosion in reinforcing steel and other metals to hinder deterioration and degradation and also extend the service life of this sort of construction materials.

Furthermore, some interesting studies report that using carbon nanotubes in small quantities in Portland cement mixes can serve as sensors to monitor the penetration of chlorides in concretes and mortars, owing to their electric and thermal characteristics (Kim, 2015).

2.3 Use of nanocomposites to repel dampness, dust, fingerprints and bacteria in construction components

The surfaces of components and materials in buildings both indoors and outdoors determine to a large extent their functionality and esthetics, offering protection from deterioration agents such as dampness, dust, bacteria, mold, sulfates, carbonatation, chlorides, salts, ultraviolet radiation, etc.

Before nano-products, maintaining and cleaning surfaces were complicated and costly; nowadays nanomaterials facilitate these tasks.

Some products we can find in the market for self-cleaning and protection of the surfaces are:

- *Lotus Effect®* (Effect which due to its hydrophobic characteristics repels water with high effectiveness in diverse surfaces such as coats for steel (if it is used in spray), paints for finishes on concrete, clay, mortar, sealants, waterproofing materials, etc.).
- *SurfaPore®* (water repellent in surfaces such as concrete, clay, block, marble, wood and even in some fibers).
- *TextileProof 250; Holmenkol®* (applications in membranes for light covers and overhangs).
- *FIBRIL Nanotubes; Hyperion Catalysis®* (used in telecommunication, electronic and information systems).
- *NG 2010®* (treatment for self-cleaning glass surfaces).
- *Pilkington Activ®* (self-cleaning glass. Variations with characteristics of low emissivity and solar control; 15-nanometer titanium oxide film).

As for hydrophobia, numerous studies have been published such as Bharat and Yong, 2011; Jeong, 2013; Barkhudarov et al., 2008; Nakajima et al., 2001, in view of demonstrating that by means of the use of some nanocomposites surfaces that repel dampness and other deterioration agents can be produced.

For the specific case of repellence to dust and bacteria, studies and works, such as an American patent (US 8961671 B2), which refers to a super hydrophobic antistatic chemical composition in the shape of a transparent film, similar to varnish, that can also be applied as spray, which greatly repels dampness and dust in various surfaces; it is based on nanoparticles as a main ingredient and also acts as anti-graffiti on surfaces such as plastic, wood, metal, ceramic, steel and even in concrete with a smooth even surface (preferably polished). In like manner, polymer nanocomposites can also be very effective in dust repelling on surfaces and finishes, as indicated by a study on polyester- and polyesterimide-based covers in combination with metallic (silver nanoparticles at 1.3% of the polymer's weight) and nonmetallic particles (polymers) that affect the material's repellence and by means of the antistatic and electric properties of the nanocomposite (Gornicka et al., 2010).

Regarding the use of nanotechnology and nanocomposites for repelling grease, for instance fingerprints on touch screens, used mostly in intelligent buildings, studies as the one by Darmanin and Guittard (2015) denote that in nature there are animals and plants which because of their characteristics repel dampness, bacteria, dust and grease, which keeps them dry and clean to adequately perform in the ecosystems they live. Likewise, nanotechnology has made it possible to repel the grease in fingerprints on windowpanes, screens and on any other similar object, in which by means of oleo-phobia materials are kept clean (Bellanger et al., 2014).

Studies on repellence to bacteria demonstrate that nanocomposites in combination with fullerene might inhibit and repel noxious bacteria, both in construction components and in pharmaceutics (EPA, 2005).

2.4 Thermal insulation and UV protection

Some nanomaterials we can find to improve thermal conditions and UV protection inside buildings and on construction components are:

- *SGG Nano*® (smart glass with ultrathin ceramic film with low reflectivity for solar control, flash control and thermal insulator).
- *Nanofilm*® (smart glass with nanocomposite films to control energy. It helps regulating infrared light).
- *Pilkington Activ*® (self-cleaning glass. Variations with low emissivity and solar control. 15-nanometer titanium oxide ultrathin film).
- *Sun Control Window Films*® (smart glass for solar control with low reflectivity, high clarity or emissivity and high heat reduction; it reflects 80 % of the total infrared radiation and 99 % of UV light).
- *Bioni Roof*® (thermal and acoustic insulation for roofs and facades; resistant to extreme temperatures, heavy dampness and frosts).
- *Nanogel Thermal Wrap*® (non-combustible thermal and acoustic insulator; also insulator in installations and pipes; 2-4 times more insulating than polystyrene, mineral wool, or cellulose).
- *NANOBYK UV absorber*® (additive to protect and coat for all sorts of surfaces exposed to solar radiation and dampness).
- *Lignol*® (prevents wood degradation from UV rays, heavy dampness and outdoor conditions).
- NANOBYK-3600®; BYK USA Inc. (improves the resistance of the elements' surface from UV radiation, mainly on wood).

Smart glass for thermal insulation and/or solar control is indubitably the most innovative product to passively save energy in buildings. Although costs are still high, there are numerous products made of nanomaterials and nanocomposites that are becoming inexpensive by the day. For example, Nanofilm® is a tested nanotechnological product with the following characteristics (table 2):

Table 2. Thermal-chromic properties of glass with *Nanofilm® NIR R-BK2085 020T0* ultrathin film

Properties	Amount
Solar transmittance	15 %
Solar absorbance	74 %
Solar reflectance	10 %
Visible light transmittance	24 %
Visible light absorbance	66 %
Visible light reflectance	11 %
U value	1.00
Shading coefficient	0.40
UV light transmittance	<= 3 %
Infrared light blocking	86 %
Solar heat gain coefficient	0.31
Total reflected solar energy (blocked)	69 %

Source: Nanofilm® products, NIR R-BK2085 020T0; http://www.nanofilm.co.kr/us/product/product0105.htm

There are many brands and sorts of smart glass commercially available, but most are made of ultrathin films with titanium oxide as a main nanocomposite added with other nanomaterials such as nano-alumina, silver nanoparticles, nano-silica or nano-vanadium oxide, as described below.

There exist other nanocomposites not fully commercialized due to the high cost to produce thin films, however they have great potential as thermal insulators in buildings, as it is the case of vanadium oxide (VO_2) as a thermal-chromic material with solar control of 43% in single layer (Yanfeng et al., 2012); the problem is that its morphology (mainly thickness) has yet to be controlled by means of innovative deposition methods.

A good option to use VO_2, owing to its excellent thermal-chromic properties, would be in combination with titanium oxide, because of its excellent thermal and dust-, dampness-, moisture-repelling properties; this way, in combination in ultrathin films (10-15 nm) excellent self-cleaning smart glass might be produced for solar control (Li et al., 2013).

2.5 In new generation photovoltaic panels and cells

Nowadays, one of the most useful and ecological applications found by nanotechnology in construction is in alternative energy; the case of direct improvements to photovoltaic cells and arrangements and other components, as conductors, batteries, converters and accessories is outstanding and has great future potential.

For example, using photo-anodized TiO_2 nanotubes, the efficiency of converting solar energy into electricity improves, thus enhancing the light-sensitivity of the cells' surface (Kuang et al., 2008).

Another example to improve photovoltaic cells is using nanomaterials such as Perovskite, Kesterite, Chalcopirite to produce new next-generation photovoltaic cells much more efficient than the common ones made of silicon (Morante et al., 2016).

With reference to forms and architectures of nanostructured materials, a nanowire arrangement offers better flexibility and scope in energy absorption which allows increasing the range of solar rays that can be utilized by solar cells, whose efficiency might be greatly increased using nanocomposites of indium nitride and gallium (InGaN) as nanowires (Wierer Jr et al., 2012), which are also utilized in the production of light sensors because of the aforementioned characteristics. The key would be the amount of gallium the nanocomposite may contain, using chemical vapor deposition in one or some layers of this nanocomposite in the surface of the cells' film (Wierer Jr et al., 2012).

Using fullerene in the production of both photovoltaic cells (and other sorts of solar concentrators) and electric conductors, photovoltaic arrangements can be improved to be more efficient in generating and distributing electricity, respectively. Likewise, batteries to store the energy produced by the photovoltaic arrangements might be improved with nanomaterials based on graphite, lithium, zeolite and graphene, owing to their excellent electrical and thermal properties.

2.6 In waterproofing, paints, adhesives, sealants for high quality and durability

Carbon nanotubes used in nano-platelets and graphene nanoparticles utilized to produce highly-efficient long-lasting waterproofing materials, adhesives and sealants, applied in windows, roofs and construction joints, offer high performance and low preventive and corrective maintenance in buildings. Also, the use of nanostructured acrylics highly resistant to outdoor conditions and impacts at present are used in skylights, domes and windows.

An instance of the use of nanocomposites in waterproofing materials in construction is to be found in a study on the synthesis of a composite made of waterproof nano organo-silicon (using in this case hetero-poly-acids); the characterization and preparation of the material was carried out through a transmission electron microscope (TEM) showing that the product is uniform and the average size of its particles oscillates between 60 and 70 nm (Bamoharram et al., 2013). This particle size allows an easy penetration into the metal pores at molecular level, thus enabling the composite's hydrophobicity. It is nonflammable and can be applied in spray or with a brush directly on the surface of many construction products such as rock, concrete, mortar, paint, plasterworks, wood, etc.

In like manner, other studies on hydrophobic nanocomposites for construction show that with the use of TiO2–SiO2–PDMS (titanium oxide – silica and poly-dimethyl-syloxane) nanoparticles with crystal sizes of up to 5 nm in diameter totally waterproof composites can be produced, which can be used in construction finishes and even to restore historical monuments (Kapridaki and Maravelaki-Kalaitzaki, 2013)

What is more, polycarbonate nanotechnology helps decreasing corrosion, dampness and oxidation of construction elements in outdoor conditions. Several nanoparticles of oxides and dioxides of titanium, ferrite, alumina and silicon work as additives in waterproofing materials and sealants for high efficiency and quality which improve the mechanical strengths and durability of construction components and systems. A study shows that using 30-nanometer titanium oxide nanoparticles on polycarbonate substrates in addition to make it hydrophobic, also makes it dust-repelling, long-lasting and more resistant (Yaghoubi et al., 2010).

The use of various polymeric nanocomposites to produce highly-efficient paints and waterproofing materials (in combination with ceramic and metallic nanomaterials) deliver good performances as paint hardeners, sealants, waterproofing materials and also as dust, dampness and bacteria repellents, as well as very effective anti-graffiti properties.

2.7 In telecommunication and illumination electronic parts and components

Nanotechnological products are so multifunctional and versatile that also include applications in illumination, electronics and telecommunications in construction. Polarizable electrodes of nanostructured materials are useful to produce supercapacitors that offer large savings in electricity. Likewise, nano-electro-structured cathodes are utilized to produce latest-generation electronical and illumination parts such as OLED (organic light-emitting diode) lightning; and in OPV (organic photovoltaic) solar cells components and other peripheral accessories.

A study demonstrates that nanocomposites such as CdSe/ZnS/CdS/ZnS can be used in the production of semiconductor quantum dots by means of a colloidal synthesis process, and so obtain electronical components (active light-emitting layers of 45 - 55 nm in thickness) to produce OLED lightning, which are latest-generation and highly energy efficient (Dayneko, 2016). Other similar study shows that using nanocomposites of materials such as tris (8-hydroxyquinolinato) aluminium (Alq3) plus bi-naphthalene (N-N') and bi-phenyl-benzidine (NPB) thin films can be obtained by means of thermal evaporation techniques and two different substrates to produce OLED lightning (Chiang et al., 2010).

Likewise, the use of nanostructured membranes in the production of high-density data storage devices, computer chips, latest-generation screens, etc.

2.8 In the production of filters, purifiers and water treatment systems

The use of nanomaterials and nanocomposites effective to treat and filter water can be divided into four types (Anjum et al., 2016):

- Nano-absorbents such as activated carbon (includes carbon, graphene, manganese oxide, zinc oxide, titanium oxide, magnesium oxide and ferric oxide nanotubes) very efficient in removing heavy metals from water
- Nano-catalyzers such as photo-catalyzers, electro-catalyzers, Fenton-process-based catalyzers (combination of H_2O_2 and iron salts) and chemical oxidizers which have demonstrated being effective to remove both organic and inorganic pollutants
- Nanomembranes such as: carbon nanotubes, electro-threaded nanofibers and hybrid nanomembranes, effective to remove paints, dyes, heavy metals and other toxic impurities

The use of nano-alumina as a part of components for water filters for treatment and human consumption is also present providing greater efficiency in filtration and treatment of water.

Studies on alumina porous substrates (AlO_2 ceramic foams) characterized by means of scanning electron microscope and depositing in them silver nanoparticles allow obtaining antibacterial filters highly efficient to purify and disinfect water for human consumption (Cabala and Acchar 2015).

The following are but some examples of nano-products in the market to filter and treat water:

- *NanoCeram*® (filtration of drinkable water, based on nano-alumina fibers and other nanomaterials; it retains 99.999% of noxious microorganisms).
- *NanoClear*® (filtration of drinkable water based on nanopolymers; it retains 99.999% of noxious microorganisms).
- *Ultra-Web*® (filtration of drinkable water based on nanofibers; it retains 99.999% of noxious microorganisms).
- *Magnetic Foam*® (magnetic foam for the remediation of soil and water polluted with oil and byproducts; it is also used in the absorption of radioactive particles).
- *CeraMem*® (waste water treatment based on nanostructured ceramic membranes modules; inorganic ultra and nano-filtration).
- *Ecosphere Ozonix*® (waste water treatment based on a reactor of oxidation, ozone and nanometric cavitation).

3.Main conclusions

- At present, nano compounds with the greatest popularity among architects and builders from all over the world are: repellents to moisture, dust, bacteria, grease and graffiti because of their immediate and relatively easy application.
- Regarding Portland-based concrete and mortars it is noticed that the addition of nanoparticles such as nano-silica or nano-ferrite, for instance, noticeably improves compression strengths and accelerates setting time; the addition of nanotubes largely improves tension and compression strengths in concretes and mortars and mainly their application is economically feasible.
- Better results are obtained with multi-walled carbon nanotubes, as they are more reinforced and include in their nanostructures multiple layers or meshes of graphene, not only a single layer as in the case of normal nanotubes.
- Magnesium nanoparticles, graphene, titanium oxide, nano-silica, powder nanozinc, cerium oxide, vanadates, phosphates, borates, montmorillonite are nanomaterials that work efficaciously to protect steel and other metals in construction as covers and inhibitors of corrosion.
- Lotus effect®, silver nanoparticles, fullerene composites, etc. are the main nanomaterials nowadays used; they repel dampness, dust, bacteria, condensation and are anti-graffiti.
- For thermal insulation and UV protection, thin films of titanium oxide, nano-alumina, silver nanoparticles, nano-silica and nano-vanadium oxide are excellent nanocomposites for these ends.
- To produce new-generation photovoltaic, cells photo-anodized titanium oxide, perovskite, kesterite, chalcopyrite, indium nitride and gallium, fullerene nanotubes and graphene offer excellent properties.
- To produce waterproofing materials, paints, varnishes, adhesives and sealants nanocomposites of carbon nanotubes, fullerene, nano organo-silicon, ferrite oxides, alumina show excellent hydrophobic and dust-repelling properties, in addition to high mechanical strengths and durability.
- Electronic parts and components of telecommunication and illumination can be improved with nanotechnology of polarizable electrodes, nano-electro-structured cathodes and nanocomposites of cadmium, selenium, zinc, sulfur which are very useful to produce OLED lightning and other latest-generation parts and devices such as solar cells, electric conductors, etc.
- To produce water filters and purifiers, nanomaterials such as carbon nanotubes, graphene, titanium oxide, ferric oxide, nano-catalysts, silver nanoparticles, chemical oxidizers as well as nanotube membranes and nanofibers remove various water pollutants in an excellent manner.
- Innovative nano-machines are being designed to take the tasks of purifying and depolluting water, soil and air to nanoscales.
- Basically, it is concluded that improvements to such materials by means of nanocomposites will depend on a number of conditions such as:
- Design, dosage, characterization and assessment of construction materials in relation to construction components and systems.
- Climate conditions and deterioration that affect the materials.
- Conditions of use and maintenance that affect the materials.
- Procedures and quality in the production and construction of the components.

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