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Nanotechnology in the construction industry

Nanotecnología en la industria de la construcción

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One of the main characteristics of our century has been the extensive development of science and technology. The discovery of the smallest and the incredibly majestic has allowed us to define the postulates that govern our science, allowing us to understand our environment. It is in this universe of the incredibly small that man has found answers to many of the problems posed by his survival. New technologies have changed the conception of the probable future that affects all areas of knowledge, including Civil Engineering. The technologies that affect this discipline are closely linked to the mastery of matter, and allow the achievement of more efficient and effective tools and materials to develop the work of Civil Engineering.

Keywords: Civil engineering, nanoparticles, nanostructure, nanotechnology, quarts, science

Una de las principales características de nuestro siglo ha sido el amplio desarrollo de la ciencia y la tecnología. El descubrimiento de lo más pequeño y lo increíblemente majestuoso, ha permitido definir los postulados que rigen nuestra ciencia, permitiéndonos comprender nuestro entorno. Es en este universo de lo increíblemente pequeño donde el hombre ha encontrado respuestas para muchos de los problemas que le plantea su supervivencia. Las nuevas tecnologías han cambiado la concepción del futuro probable que afecta todas las áreas del conocimiento, incluida la Ingeniería Civil. Las tecnologías que afectan esta disciplina están muy ligadas al dominio de la materia, y permiten la consecución de herramientas y la obtención de materiales más eficientes y eficaces para desarrollar la labor de Ingeniero civil.

Palabras clave: Ciencia, ingeniería civil, nanoestructura, nanopartículas, nanotecnología, quarts

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Introduction

Nanotechnology encompasses those knowledge and techniques that humans are developing to observe, characterize, understand, predict, and use the properties of nanometric-sized structures (Becerra et al., 2019; Garcia, Osuna, & Martinez, 2018; Ye, Zuo, & Fan, 2018). A nanometer (1 nm) is one-billionth of a meter, a really small length in which we could only align a few atoms. This new discipline has the nanoscale (or nano-world) as its setting, which can be defined as the range of lengths between approximately 1 and 100 nm.

The nano-world is populated by nanostructures and nano-objects that manifest interesting phenomena, which would not appear in them if their size were much larger (Gordillo & Martinez, 2018; Mobasser & Akbar, 2016). It is easy to understand how as a structure becomes smaller the relative fraction of atoms located on its surface increases, giving it different properties (Ali, Negin, & Xie, 2016; Contreras, Rodriguez, & Taha-Tijerina, 2017). Besides, we have to take into account other phenomena that only the intriguing Quantum Mechanics can explain. By controlling the geometry and size of the nanostructures and nanospheres, it is possible to modify the electrical conductivity, coloring, chemical reactivity, elasticity, etc., of many materials (Serena, 2012).

Precursors of the application of nanotechnology

In the field of modern physics, two personalities have distinguished themselves by offering the vision of the future that currently governs the conditions and objectives of materials research. One is the physicist Richard P. Feynman, the other is the theoretical physicist Freeman J. Dyson. Both have made important contributions to the body of knowledge of mankind. For example, Feynman won the Nobel Prize in Physics in 1965 for his research in quantum electrodynamics that contributed to the understanding of elementary particles within the field of high-energy physics. On the other hand, Dyson published in 1979 his renowned theory that deals with the deterioration of ordinary matter in a universe whose main characteristic was a continuous and permanent expansion. However, in the field at hand, the creation of new and incredible materials, both showed at the time a visionary conception of the future.

On December 29, 1959, Richard P. Feynman presented a paper at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech), where he worked as a researcher. The full text of the lecture was intended to explain the problems and advantages of manipulating and controlling objects in nature at microscopic scales. First, he talked about writing all the pages of the famous Encyclopedia Brittanica with atoms on the head of a pin. He pointed out the need for the existing microscopes of that time to be improved to observe objects with 100 times greater magnification. He compared the information stored in a DNA helix with the incipient information handled by the computers of his time, raising the need and the possibilities of electronic miniaturization. He talked about industrial processes of solid evaporation to generate new types of materials. He mentioned the consideration of building atom by atom microscopic machinery to fulfill predetermined functions. The most important aspect of his presentation was the affirmation that as long as human beings had control over the arrangement of molecules and their atoms, new materials with properties unimaginable at that time could be created. In the end, he instituted two awards, still in force, with a permanent fund financed by himself, to recognize any attempt at miniaturization on the scales he had proposed.

On May 16, 1972, Freeman J. Dyson was invited to give a lecture in honor of the writer J. D. Bernal3 at Birbeck College, London, when he was a researcher at the Institute of Advanced Studies in Princeton, New Jersey. In this lecture, he praised Bernal's vision and compared him with Verne regarding many technological developments that have taken place in the present century. However, the essence of his lecture was to discuss the three possible paths that emerging biological technology could take in the future, according to his point of view. The first path he mentioned was the feasibility of what he called genetic surgery, a procedure by which biologists would be able to modify, graft, or remove DNA sequences from living beings to recompose or alleviate their physical structure. The second way was called biological engineering, and it consisted of using genetically redesigned living microorganisms to extract minerals and produce materials through the process of common fermentation. The third and last path he exposed was the self-reproducing machinery, which consisted of imitating the function and reproduction of a living organism with non-living materials on any scale.

Both Feynman and Dyson, for their creative contributions and concepts based on totally scientific facts and knowledge, are currently considered the fathers of so-called nanotechnology. This term refers to a wide range of novel technologies in which materials and objects are manufactured with dimensions between a micrometer and a manometer of length or diameter. Their early joint vision of the future of molecular and biological technology opened up overflowing hopes in the world's scientific communities, regarding the future transformation of industry, materials research, the conservation of terrestrial ecology, the development of cybernetics and space exploration (Ocampo, 1998).

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Some nanomaterials in construction

The nano-concrete

Traditional concrete can be converted into a Nano-Concrete by the following procedures: addition of nanoparticles to the cement, reduction of the cement particles to cement-nanopowder, hybridization of the hydrated calcium silicate (C-S-H), or the incorporation of nano-reinforcements such as nanotubes or nanofibers.

Addition of nanoparticles

There are several nanoparticles, but the most common are Nano Silica (n.SiO2), Nano Titanium Oxide (n.TiO2), Nano Ferric Oxide (n.Fe2O3), Nano Aluminum Oxide (Alumina) (n.Al2O3), and the Nano Clay particles.

The addition of Nanoparticles to the cement has a very remarkable influence on its hydration process, at all scales: nano, micro, and macro, of the chemical compounds that are generated, modifying their structure; this influence includes the nano and microstructure of the (C-S-H) gel, which have a very remarkable effect on the resistance of the concrete at a macro scale.

The Nanoparticles fill the gaps between the cement grains and between the aggregates and act as active cores that increase the hydration of the cement, due to the great reactivity of its surface; they improve its resistant properties, reduce its porosity and the retraction of the concrete that causes its cracking as well as its possible later degradation.

The addition of Nanoparticles also increases the quantity of (C-S-H) of high density, present in the cement paste and decreases the quantities of calcium hydroxide Ca (OH) 2 and the quantity of (C-S-H) gel of lower density; the presence in the concrete of greater quantities of (C-S-H) gel of very high density, increases the resistance to the dissolution of the calcium carbonate of the concrete matrix.

The manufacture of cementitious nanoproducts (nano binders), composed mainly of finely pulverized mineral products such as flying ashes, silica smoke, metakaolin, nano-silica, with the addition of 20%-30% of finely pulverized portland cement, to fill the gaps between the particles of mineral additives, will provide nano products with greater cementitious power and cementitious materials with properties far superior to those of current cement. These new cementitious nanoproducts will significantly reduce CO2 emissions, produced in the manufacture of portland cement with lower energy consumption; they will also reduce the consumption of traditional raw materials, mainly limestone, and the reduction of portland cement clinker.

Properties of the nano-concrete according to the added particle

SiO_2

Improves workability by adding a superplasticizer. More waterproof concrete. Greater resistance to the dissolution of calcium carbonate. Increase of the resistance to compression up to 26%, at 28 days. Increase of the resistance to flexion. Increase in the speed of setting.

TiO_2

Self-cleaning capability. Capacity to eliminate pollutants in the environment such as NOx, CO2 (Photocatalysis), in facades, road pavements. Accelerates the hydration of the cement at an early age. Increases the resistance to compression, bending, and abrasion.

Fe_2O_3

Auto-detection of the compression stress supported. Real-time control of the tensional state without using sensors. Intelligent structures.

Al_2O_3

Increase of the Modulus of Elasticity up to 140%.

Processed clay

A very important increase of the compression and traction resistance of the cement mortars. More waterproof concrete. Resistance to chlorides. Self-compacting concretes. Reduction of shrinkage. Increase of the resistance, after the first fracture, using exfoliated clay particles covered with a PVA layer.

Reduction of cement particles to cement nanopowder

There are two procedures: High energy comminution of Portland cement clinker (top-down) and chemical synthesis (bottom-up). NanoConcrete has cement particles of size <500 nanometers. Properties of NanoConcrete Among its properties we have: Processed at room temperature, heat resistance (>600ºC), reduction of autogenous cracking, a drastic reduction of CO2 in its manufacture, higher initial and final compression and traction resistance, good workability, no need to use superplasticizers, higher resistance to segregation, greater acceleration of hydration, better bonding between the aggregates and the cement paste, increased toughness, and shear, tensile and flexural strength, very good chemical compatibility with carbon nanotubes to make *smart concrete* and greater durability.

C-S-H hybridization

The hybridization process modifies the structure of the hydrated calcium silicate (C-S-H) of the cement by three different processes: inserting organic nanomolecules in the structure of the (C-S-H) gel, inserting *invited nanomolecules* to establish covalent bonds with the structure of the (C-S-H) gel and inserting *invited nanomolecules* in the places of the chain of the (C-S-H) gel, in the points that have defects and in the spaces between layers. Nanotechnology concretes are also manufactured incorporating nanotubes or carbon nanofibers (CNTS, CNFS).

These nanomaterials, due to their extraordinary mechanical properties, also electronic and chemical, can increase the mechanical properties of cementitious materials, such as Young's modulus by the high modulus of carbon nanotubes (1.0 TPa) and tensile strength; in addition, they can give cementitious materials other important properties, such as: serving as a shield for electromagnetic fields and the ability to turn them into *smart* materials The system can perform a self-check, in real time, of its state of cracking, of its tensional state and of its deformation during its useful life. Nanomaterials have the capacity to significantly increase the properties of cementitious materials, due to their high specific surface (up to $600m^2/g$) and their high slenderness index (>1000), with the potential to practically eliminate the autogenous cracking that occurs in concretes and mortars during the hardening process, distributing the stresses generated by the entire mass of the cementitious matrix.

Nanostructured steel

The tensile strength of traditional steel barely reaches 10% of its theoretical value (27.30 GPa) as a result of defects and impurities in its internal structure, which originated during the manufacturing process.

At present, the so-called Nano-Structured Steel is already being manufactured, using a new manufacturing technology that manipulates, at a nano-scale, its structure during the complex manufacturing process.

The new manufacturing technology achieves a reduction in size and a greater uniformity of the microcrystals that are formed, eliminating or reducing the defects in the crystals (size 100-200 nm) If there is any microcrack or discontinuity during manufacture, it will be very thin in width and very small in length, covering a smaller area within the mass of steel. The modification of the microstructure is produced by the addition of self-assembling nanoparticles (e.g., copper nanoparticles) on the edges of the steel grains. Another technique for modifying the structure of the steel to make it more compact, uniform, and practically defect-free, is to subject the steel to a process of severe plastic deformation. Some types of nano-structured steel are currently manufactured, such as Microcomposite Multistructural Formable Steel (MMFX), bainitic steel, Advanced high strength steels (AHSS), Nanostructured ODS ferritic steel (European project), martensitic steel, and High Resistance, low carbon steel for building construction, which incorporates nanoparticles of copper (Cornejo, 2015).

Nanotechnology in the construction industry

Nanotechnology has been implemented in different industrial sectors, although some experts believe that the construction sector has presented a certain lag compared to areas such as electronics, automotive, and pharmaceutical chemistry, in which consolidated and even marketable results have been obtained. This is pointed out by Dr. María José López Tendero, who was coordinator of the Construction Technology Institute (AIDICO), based in the city of Valencia, Spain, and is currently co-founder of Laurentia Technologies (a company specialized in the development and manufacture of nanomaterials), which establishes that the main advances in construction are in the scientific field. The nanoscience of cementitious materials has been studied with greater interest, with an increase in the knowledge and understanding of nanoscale phenomena (for example, the structure and mechanical properties of the hydrated phases of cement, the interfaces in concrete, and the mechanisms of degradation). Progress has also been made in the knowledge at the nanoscale, thanks to the use of techniques such as electronic microscopy, atomic force microscopy, nuclear magnetic resonance, among others. Concrete can be nano-modified through the incorporation of nanomaterials to control the behavior of the materials and add new properties, or through the modification of molecules in the particles of cement, aggregate, and additives to provide new functionalities. Among them are: low electrical resistivity concretes, self-sensing capabilities, self-cleaning capabilities, microcracking self-repair capabilities, corrosion self-control, etc., the expert points out (González, 2014).

Addition of nanoparticles to Portland cement

Characteristics of nanoparticles

Nanosilica (NS). They are nanoparticles (1 - 500 nm) of amorphous SiO_2 that are insoluble in water. Size, size distribution, and specific surface area are parameters that are defined according to the synthesis process (Björnström, Martinelli, Matic, Börjesson, & Panas, 2004). Thanks to its properties, nano-silica has become the most reactive silica material, so it has been added to materials such as polymers to increase their mechanical strength, flexibility, and resistance to aging (Tobón, Restrepo, & Payá, 2007).

Researchers looking for maximum reactivity used in their NS commercial projects of low crystallinity as shown by

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XRD (Fig. 1), with purities equal to or greater than 99.9%, specific surface area between 160±20 m^2/g and 640±50 m^2/g, density around 0.15 g/cm^3 and average diameter of particles between 5 nm and 20 nm. The addition percentages were generally between 1% and 12% by weight, 1%, 2%, 3%, 5%, 6%, 10% and 12% were used, worked with constant water/cement (a/c) ratio and used commercial superplasticizers (Tobón et al., 2007). Among the few who deviated from this scheme are (Shih, Chang, & Hsiao, 2006) who added percentages of nano-silica below 1% (0.2%, 0.4%, 0.6%, and 0.8%), varied the a/c ratio (0.25, 0.35, 0.45, 0.55 and 0.65) and did not use superplasticizers and (Byung-Wan, Chang-Hyun, Ghi-ho, & Jong-Bin, 2007) who used thicker NS (40 nm and 60 m^2/g) in their project (Kalinski & Hippley, 2005).

Others. In (H. Li, Zhang, & Ou, 2006) they used commercially α nano alumina, greater than 99.99% purity, particles below 150 nm, specific surface of 10±5 m^2/g, and density between 0.3 and 0.5 g/cm^3. It used 3%, 5% and 7% substitution. With constant a/c of 0.4 and cement/sand 1:1. (H. Li et al., 2004) used commercial nanometric iron particles of 30 nm. In percentages of 3%, 5% and 10% by weight. (H. Li et al., 2006) used commercial low-crystallinity nano-titanium (anatase) of 99.7% purity, specific surface 240±50 m^2/g, density between 0.04 and 0.06 g/cm^3, and an average diameter of 15 nm. In percentages of 1%, 3% and 5% by weight (Knofel, 1979).

Incidents in physical properties

(Qing, Zenan, Deyu, & Rongshen, 2007) found that by increasing the percentage of the addition of NS the consistency of the paste decreased slightly and that the opposite occurs with the addition of SF, i.e., NS accelerates the hydration process compared to SF. This is supported by authors like (Björnström et al., 2004) and (H. Li et al., 2004) who found that silica in nanometric sizes accelerates the hydration process and the formation of tobermorite (C-H-S) thanks to its high surface energy (Ganjian & Pouya, 2005).

(H. Li et al., 2004), through microstructural analysis, determined that the samples with higher resistance present denser and more compact textures because the nanoparticles filled the pores (H. Li et al., 2004).

Something similar was found by (Wen-Yih, Jong-Shin, & Chi-Hsien, 2006) when they used organomodified montmorillonites and verified that the permeability was reduced by up to 100 times. It should be highlighted that montmorillonites are microparticles and not nanoparticles, so they can only penetrate up to 0.1 μm pores. This is physically demonstrated in the work of (Ji, 2005) who compares the penetration of water in a normal concrete against one added with NS and finds that in the latter the penetration is significantly lower 146 mm and 81 mm respectively (G. Li, Wang, & Zhao, 2005).

Impact on mechanical properties

Most researchers accept that by increasing the nano-SiO_2 content in portland cement, a substantial improvement in the development of compressive strength is obtained, especially at an early age (3 days). When this behavior is compared with the one presented with the addition of silica smoke, it is noticed that the NS is much more reactive, that is to say, they have more pozzolanic activity (Byung-Wan et al., 2007; H. Li et al., 2004; Qing et al., 2007; Shih et al., 2006).

Impact on mineralogy

In general, the different authors have found that increasing the addition of NS reduces the number, degree of crystallinity, and size of portlandite crystals (Björnström et al., 2004; Byung-Wan et al., 2007; Ji, 2005; H. Li et al., 2004; Qing et al., 2007). They also state that the pozzolanic activity of nano-SiO_2 is higher than that of silica fume, this is irrefutable knowing that pozzolanic activity depends on the composition (silica is the most indicated compound because of its chemical affinity with calcium and its possibility of forming calcium silicates - NS is generally of higher purity than SF), low crystallinity, and specific surface (where NS is much higher). Therefore, the NS can react with the CH crystals formed in ITZ and produce C-H-S, that is, a more stable structure. Thus, the number and size of CH crystals are significantly reduced and the resistance at early ages is increased (McCarthy & Dhir, 2005).

Percentage of addition

In the case of the NS, it can be stated that there is no consensus on what is the most appropriate percentage of addition. Some authors propose that low percentages of addition are better, such as (Shih et al., 2006) who propose 0.6% as the optimum percentage of the addition of NS, to achieve maximum resistance to compression, (H. Li et al., 2006) who found the best results of resistance to bending and compression with 1% of the addition of NS and NT and (Qing et al., 2007) who say that 3% is sufficient to achieve good assimilation of HC. On the other hand, some recommend higher percentages such as (Byung-Wan et al., 2007) and (H. Li et al., 2004) who find significant improvements with additions close to 10% of NS (Mostafa & Brown, 2005).

The nano-trend

Nanotendence in the construction industry can be defined as the trend to use processes to improve material characteristics through the use of nanotechnology.

The best-known process of the nano-trend in the improvement of construction materials is tempered glass that thanks to the implementation of nanotechnology improves its resistance to fracture.

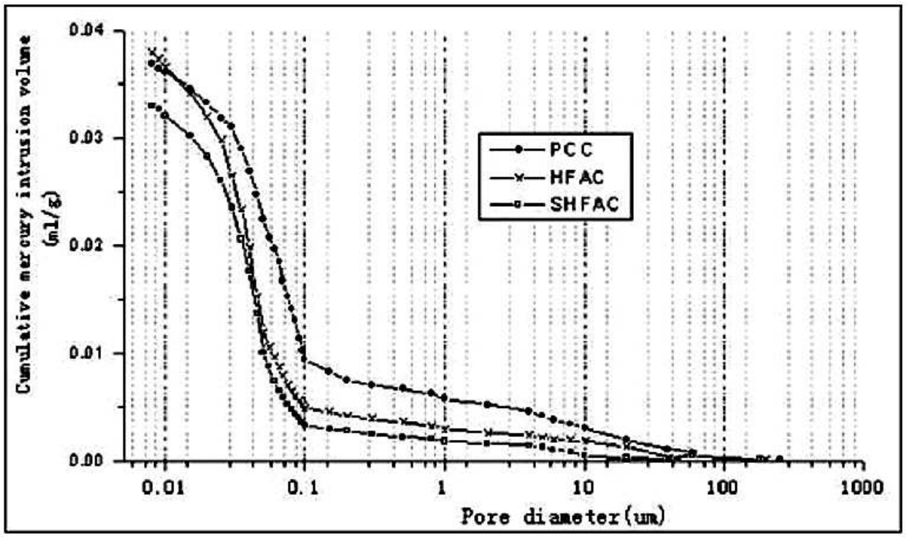

Figure 1. Porosity measurement at 2 year. PCC concrete of Pórtland cement; HFAC concrete with high volumen fly ash (50%); SHFAC concrete with high volumen fly ash (50%) blended with nanosilice (4%) (H. Li, Xiao, & Ou, 2004).

Correctly applied, the nanotendence can improve many materials, from the dispersion of particles in cement to reduce the percentage of water contained in it, improving its strength, to helping materials such as wood with great affinity to absorb and retain water, modifying certain aspects until it becomes hydrophobic, making it repellent.

The benefits that nanotendence can present in the industry can be presented in different ways depending on the point of view that needs to be analyzed. In the structural point of view, we can find that the use of nanotechnology is optimal and recommended, the use of materials with implemented nanotechnology produces less waste thus helping cities and industries by reducing pollution, nanotechnology implemented in the field of construction industry offers practical solutions in the short, medium and long term (Calleja, 2001).

In addition to its great advantages over materials of the same nature exempt from these technologies improvements such as increased durability, strength, hardness, waterproofing, etc.

From an innovative point of view, we have the great technological advance that is implemented today thanks to nanotechnology reaching fields previously unexplored in the industry, and the feedback that can be presented thanks to the possibility of combination in building materials with nanotechnology innovations that can promote new techniques, materials, processes, and styles in construction (Collepardi et al., 2005).

Conclusions

Today it is possible to find many materials that are used in construction to which currently in its development is applied nanotechnology such as:

- The concrete.
- Cement paste.
- Paints and varnishes.
- Carbon nanotubes.
- Ceramics.

In short, it can be concluded that the implementation of nanotechnology in the field of the construction industry, civil engineering, and architecture has brought innovation in the process of doing things in certain ways giving us more and better options to choose when we want to undertake a project.

Despite this, the use of nanotechnologies in construction has certain risks at the time of its use, it is the contamination that can be presented in different areas of nanotechnology and nanosciences, this when the nanoparticles in the air make contact with living organisms, where such cases could cause damage to health and the environment, Despite the few studies that have been carried out in this field, given its relative proximity to the present, the harmful effects on health and the environment have already been identified. Among the major sources of pollution are ash produced in combustion processes, metals in mining and construction, batteries and cells in the energy industry, and unusable batteries in the automotive industry.

It can also be stated, considering the advances that have been achieved thanks to the nano-trend, its benefits, and risks that can be found in its use, that the implementation of nanotechnologies should be sought in other aspects within civil engineering to achieve more advances, realizing

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that the implementation of this brings more positive than negative aspects in the construction industry, thus giving way to nanotechnology to improve processes and innovate the methods and forms that are used today in the industry.

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