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Nanotechnology Applications in the Construction Industry

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ABSTRACT

With the ever-growing population, increased number of constructions and the limited resources and building materials being used, the demand for using new materials in the construction industry has increased. Attempts that are made to find solutions for improving the quality, increasing the efficiency of building materials along with reducing the consumption of energy and raw materials have led to applying novel technologies in this industry. In recent years, researchers, who are active in the construction industry, have shown interest in the various applications of nanomaterials with the purpose of improving the characteristics of building materials. The introduction of nanotechnology-based products has been accompanied with a giant leap toward well-being and the quality of life and has resulted in huge economic movements. Different nanomaterials can improve the fundamental characteristics of building materials which include quality, strength, durability and being light-weighted on one hand and to provide important characteristics and functions such as heat insulation, self-cleaning and anti-fogginess, on the other. Also, using this technology helps saving energy and eventually, economizing in the whole construction industry. In the present research, it has been tried to study those building materials that are both structural and non-structural, are manufactured by nanotechnology and are optimized based on this knowledge along with the advantages of using this technology in producing new construction products.
KEYWORDS: Nanotechnology, Nanomaterials, Construction Industry, Building Materials.

1. 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, 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. At the moment, the ever-increasing need of the society to houses and buildings has made the need for applying new methods and building materials with the purpose of increasing the construction speed, using lighter materials, the useful life of buildings and strengthening them against earthquakes more urgent.

Alongside two other great changes, i.e. genetics and IT, nanotechnology forms the fourth wave of the industrial revolution. Estimations reveal that construction equipment gives an annual income of 1,000 billion dollars. Therefore, the construction industry is one of the important industries in which nanotechnology and nanomaterials can have extensive applications.

2- Definition of Nanotechnology

The term Nano is derived from the Greek word Nanos (in Latin Nanus) meaning dwarf. This word is a prefix that just like other prefixes comes at the beginning of the units of measurement such as second, meter, etc. Therefore, similar to prefixes like centi-, deci-, deca-, kilo-, mega-, etc. 'Nano' is an indication of scale. One nanometer (1nm) means 1×10^{9} (one billionth of a meter) or 10 angstroms, which is equal to the size of 5 atoms. "A water molecule is about one nanometer in diameter. The diameter of a one-layer

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tube is 1.5 nanometers. The tiniest transistors are 20nm in size. The DNA molecule is 2.5 nm wide and proteins are 1-20nm in size"[1].

Nanotechnology is a name given to a kind of productive IT. As the name implies, it is achieved when the ability to make objects from atoms exists and rearranging materials with atomic precision is possible. Of course, up to now, no specific internationally applicable definition for nanotechnology has been suggested, but what everyone agrees upon is that it is an analysis and research on substances in nanoscale. Therefore, whatever research is done under 100nm scale would be an indication of nanotechnology. " The Ministry of Education and Federal Research in Germany has described nanotechnology as this: 'Nanotechnology covers all research, surveying, producing and application activities which are related to molecular structures that range from inner to outer surfaces of a substance, where at least one of its dimensions have a tolerance level of less than 100nm. Obviously, manipulation of the nanoscale parts of a system leads to creating applications and characteristics in substances by which developing new building materials or applications for the old ones could be achievable"[2].

3- Areas of Nanotechnology Applications in the Construction Industry

Construction industry is one of those industries in which nanotechnology can have many applications. With its requirements in terms of strength, resistance, durability and high efficiency, this industry is considered as one of the main users of nanostructures. It is expected that in a not too distant future, nanotechnology would make the functional extent of building materials take a huge leap in areas like energy conservation, light, safety and being smart. Perhaps, the early stages and steps of progress in the world of nanotechnology could be able to change the nature of building materials and even evolve our construction methods in a way that buildings would be constructed to be more compatible with the environment and users. Undoubtedly, by having reinforced building materials such as carbon nanotubes, one can reconsider his designing methods and the expected functions of a building. For instance, it might be possible to completely exclude the main difference between the building structure and its shell and also, with the help of strong building materials that can act as both the skeleton and the outer shell, many of the limitations with which engineers are faced can be removed.

"As a whole, some of the areas of the construction industry in which nanotechnology can cause developments could be summarized as follows:

- Producing strong and smart building materials besides repairing and reconstructing the existing structures.
- A new and innovative system which causes the 'Design-Production-Operation-Destruction' chain in construction to optimize. This is achieved by developing new tools based on information technology.
- New technologies to process multi-cultural products/functions.
- New methods to produce substances and building materials that have a significant effect on reducing water and energy consumption and would produce much less wastes. Moreover, developing environment sustainability-based production methods that can recycle constructional products and by-products is one of the areas which nanotechnology has influenced.

Those who are in charge and active in the field of construction, predict that in 10-15 years time, nanotechnology would be able to have important effects on the construction industry.

- Increased understanding of architects of the nanoscale and its effects.
- Modified nanoscale substances and building materials.
- Strong and super-strong structural building materials.
- Multi-purpose thin films, coatings and paints.
- Multi-purpose building materials and compounds.
- Novel tools, production and controlling methods for manufacturing building materials and by-products.
- Smart structures and using microsensors.
- Integrated monitoring and diagnosis systems.
- Lighting systems that save energy, fuel cells and communication and computation devices"[3].

"**Table 1**- Areas of the construction industry in which nanotechnology is the main source of influence"[4].

Areas of technology and research that are related to nanotechnology	Applications	Desired Qualities
Nanostructure substances and building materials: • Porous nanomaterials (often cement or wood-based) • Polymers • Composites	Generally, in building materials; insulators; carrier building materials.	• Being multi-functional • Increased resistance- weight ratio • More durability and sustainability • Fire-resistant • Self-cleaning • Improved quality of the air inside and outside the building • Recyclable
Nanostructure surfaces (coatings and films): • Causing chemical changes in surfaces • Causing physical changes in surfaces	Every application in construction and development projects (except for reconstruction and renovation)	• Being multi-functional • Increased resistance and hardness • Durability • Improved quality of the air inside and outside the building • Self-cleaning
• Energy production and storage • Solar cells • Fuel cells	• Cooling and heating systems in the building • Supplying electric energy	Efficient in terms of producing and consuming energy inside the building and other constructions
Nano-optics: • Flat, light wave circuits • Photonic crystal fibers • LEDs, OLDs, QLEDs • Optical sensors hidden inside building materials	• Integrated functions of electronic and lighting systems • Controlling the environment	• Efficient in terms of energy consumption • Protection against fire and other hazards
Nanosensors: • Biosensors • Optical sensors • Chemical sensors • Microorganism sensors • Electroactive materials	Monitoring and controlling every variable in a building and other development projects	• Possible to be hidden • Durability and sustainability • Easy maintenance • Efficient in terms of energy consumption and to preserve energy resources

4- Applications of Nanotechnology in Structural Building Materials

4.1- 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. Experiments 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"[5]. To improve concrete properties, two nanotechnologies are introduced here:

4.1.1- 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"[6]. 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 microcracks in bridge and dock columns"[7].

4.1.2-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"[8]. 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.

4.2- Steel

Besides concrete, steel is one of the other important structural building materials which are either used in concrete or by themselves. Unique characteristics such as strength, weldability and resistance to erosion have made it a suitable building material. At the moment, we can see how nanotechnology is making steel more resistant to corrosion and erosion." MMFX is a type of steel whose nanostructures are modified and compared with the ordinary steel has a completely different nanostructure. It has a multi-layer structure like that of multi-layer boards. This unique structure is three times stronger, has more ductility capacity and its resistance to corrosion is five times more than that of the ordinary steel. Such properties make this type of steel a suitable option for using in concretes. Also, its being stronger has caused it to be less used relative to the ordinary steel"[9].

"Another steel-related product in nanotechnology is Sandvik Nanoflex, whose elasticity coefficient and strength are much greater and helps producing lighter and thinner compounds relative to aluminum and titanium. This product is stainless too. At first, it was used in medical supplies like surgical needles. The said product's being highly resistant to corrosion keeps its maintenance costs quite low"[10].

5-Applications of Nanotechnology in Nonstructural Building Materials

5.1- Nanocoatings

"Smart nanocoatings are one of the most important achievements of nanotechnology in the field of producing materials. In addition to their various and multi-purpose functions, nanocoatings are quite effective in saving energy and in reducing the costs. They can turn every surface to a smart, anti-corrosion, anti-radar, anti-fog (and mist), air purifier, surface cleaning and an active biological coating. Benefiting from active nanoparticles such as titanium dioxide in their structures, these coatings are capable of showing smart protective, healing, absorbing, repulsive and neutralizing reactions to environmental stimuli such as light, heat or sensitivity to some chemical changes like corrosion"[11]. Photocatalytic coatings that mainly contain titanium dioxide have interesting characteristics some of which are as follows.

5.1.1- Self-cleaning Tiles and Ceramics

In recent years, researchers have identified nano-metallic compounds with anti-bacterial properties which can prevent the growth of bacteria, fungi and other pathogens. Some of the applications of these properties are in producing hygienic tile and ceramic glazes because ceramic coatings are often in contact with foods, drinks, fluids and wastes which are important factors for the growth of various bacteria. On the other hand, presenting an ideal and efficient compound of nano-photocatalysts with anti-bacterial property and using it in public places such as hospitals can prevent the spread and pathogenesis of bacteria. Therefore, besides preventing disease outbreaks, treatment costs can be reduced as well.

5.1.2-Nanotechnology-based Glasses

Among nanotechnology applications that are related to glass products, self-cleaning and anti-fog coatings can be mentioned. The problem of polluted surfaces, especially in those surfaces with high energy levels such as glass that absorb other molecules is quite widespread. The strategy that nanotechnology suggests is using organic/mineral nanocomposites which create the characteristics of perfluorated polymers (such as Teflon). Also, using titanium dioxide nanoparticles in glass causes pollutants from air and the surrounding environment to be absorbed and broken down to safe volatile gases.

"It should be said that using nanotechnology in glasses leads to producing energy-controlling glasses, which conserve energy and can reduce the its loss by 80%. Less heat transfer compared with ordinary insulated glasses and transparency are some of the other characteristics of these glasses. They pass the visible part of the light spectrum and prevent the transfer of its heat, infrared and ultra-violet lights and finally, reflect them"[12].

5.1.3- Nanofoams

"Nano foam coatings are one of the other products of nanotechnology for construction. They are designed with the purpose of sealing and protecting constructional and industrial surfaces against erosion and corrosion. Preventing the growth of molds, bacteria and harmful microbes on building surfaces, protecting the outer façade against environmental pollution, preventing fogginess and strengthening glass surfaces against thermal shocks are some of the characteristics of nano foams"[13]. Regarding the interior design, painting the surfaces with titanium dioxide-based paints that contain nanoparticles would protect the walls against blisters, spots, rust and other surface damages.

5.1.4- Surface Insulators

Working with insulators is based on having so many pores so that they can keep as much air as possible. Insulators use the air's low conductance property to stop its free flow. In this regard, nanopore materials have very interesting characteristics among which thermal insulation against all three forms of heat, i.e. radiation, conduction and convection can be mentioned. "A special property of these products is their fluidity which makes using them on metallic and non-metallic surfaces possible. That is why nanocoatings for insulating applications with their minimum thicknesses of a few thousandths of an inch are more effective than ordinary insulators such as fiberglass and polyester and don't have any harmful effects"[12].

5.2- Nanosensors

Nanosensors are sensors with nanometer dimensions, which due to their small and nanometric dimensions enjoy very high precision and reactivity in a way that, they react at the presence of even a few gas atoms. Today, powerful sensors of the nanotechnology generation are capable of controlling temperature, humidity and suspended toxic particles in the air.

It wouldn't take much time until vibration and blister controlling sensors along with other functional considerations in construction would enter the market. Nanotechnology is rapidly improving the functional speed of the cells and other wireless devices in these sensors. In a not too distant future, sensors will be used in buildings with the purpose of collecting information about environment and constructional applications. In this way, the consisting elements of buildings would become smart. Nanotechnology-based sensors can in turn have many applications in concrete structures. In order to control concrete quality and durability, these sensors can be designed for various purposes such as measuring the density, concrete slump and parameters like temperature, chlorine concentration, pH, carbon dioxide, tension, rebar corrosion and vibration.

6- Conclusion

With consideration of what has been said in this article, it is quite obvious that using nanotechnology and combining it with the construction industry has a bright future ahead and is rapidly developing and evolving. Hence, it requires special attention. Practical results of developments in the field of nanotechnology could lead to manufacturing equipment that are greatly different from the past and would create a completely new generation of materials with unique capabilities.

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.

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