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Nanotechnology in Civil Enginering Present Scenario With Practical Application

Engineering

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ABSTRACT

"Nanotechnology", the term itself signifies very minute particles that is being combined with this era of technology giving us the ultimatum - NANOTECHNOLOGY. Thus, this is nanotechnology will help us control and conquer the smallest of the material, therefore, eliminating the limitations in the field of civil engineering helping to improve this difficulties and help nanotechnology make a great leap, especially in India. This paper describes an over view of the nanotechnology in the various fields of civil engineering along with the real time practical application. It gives a surface view of the types of nano materials along with its initiatives in India. Here, we get an in-depth of the real-time application of nanotechnology in building materials like concrete, carbon nanotube, steel, wood, coating, glass etc. Nanotechnology can also be used in the new emerging trend of green building, especially in India. The employment of nanotechnology in the areas of safety precautions like fire protection and thermal insulation are also mentioned. The impacts of nanotechnology on construction in the present scenario are also departed in the following.

INTRODUCTION:

In India, need for new constructions both for housing and for infrastructure sectors, necessitates large-scale use of engineered construction material. Hence, it is not surprising that India is second largest producer and consumer of cement after China and this production is likely to increase significantly, as the per-capita consumption of cement in India is lower compared to world average per capita consumption. Concrete is the most popular construction material because of its versatility and relatively low cost, and this is another reason for likely large-scale increase in its use in Indian construction in near future. The negative impact of cement productions for the world is the CO2 emissions, which has resulted in direct effects to global warming, raw materials depletion and energy consumption. Cement manufacturers are a source of greenhouse gas emissions, accounting for around 7% to 8% of CO2 globally; hence, there is a serious need for adopting construction methods which take care of sustainability aspect.

Nanotechnology is a promising research fields that may significantly improve the mixture design, performance and production of cement-based materials. Materials composed of nano-sized particles displays unique physical and chemical properties compared to those with normal particle sizes.

Nanotechnology can be used for design and construction processes in many areas since nanotechnology generated products have many unique characteristics. These characteristics can, again, significantly fix current construction problems, and may change the requirement and organization of construction process.[2] These include products that are for, Lighter and stronger structural composites, Low maintenance coating, Improving pipe joining materials and techniques, Better properties of cementite materials, Reducing the thermal transfer rate of fire retardant and insulation, Increasing the sound absorption of acoustic absorber, Increasing the reflectivity of glass.

The applications of nanotechnology in construction will provide a meeting point for technocrats, engineers, scientists, academicians, entrepreneurs, where on one platform, a blend of all of them can discuss on several issues providing them a common platform that is necessary to meet the challenges of our country in particular and the world in general. This event features the best interdisciplinary research, applied practices and emerging technologies and management issues.

TYPES OF NANO MATERIALS:

i) Titanium dioxide (TiO2)
ii) carbon nanotubes (CNT's)
iii) nano silica(ns)
iv) polycarboxilates
v) nano Zro2,etc

Two nano-sized particles that stand out in their application to construction materials are titanium dioxide (TiO2) and carbon nanotubes (CNT's).

HOW NANOTECHNOLOGY IS USED IN CIVIL ENGINEERING

Nan technology has many applications in the engineering field, especially in the area of civil engineering. A vast number of materials can be enhanced by the use of nanotechnology, some of which include glass, concrete, and steel. Nanoparticles can also be used in coatings such as paints to give the coating "...self-healing capabilities and corrosion protection under insulation. Since these coatings are hydrophobic and repel water from the metal pipe and can also protect metal from salt water attack".

NANOTECHNOLOGY INITIATIVES IN INDIA

The emergence of nanotechnology in India has witnessed the engagement of a diverse set of players, each with their own agenda and role. Nanotechnology in India is a government led initiative. Industry participation has very recently originated. Nanotechnology R&D barring a few exceptions is largely being ensued at public funded universities as well as research institutes. An overview of the key players engaged in nanotechnology in India is given in the Figure 1. Given the enabling nature of nanotechnology and ability to develop along with existing technologies, it has the potential to be utilized as a tool to address key development related challenges in diverse sectors like energy, water, agriculture, health, environment and the like. Enabling energy storage, production and conversion within renewable energy frameworks has been cited as the primary area where nanotechnology applications might aid developing countries. Nanotechnology interventions might be sought at specific junctures to improve quantity and quality of water and wastewater treatment systems. Enhancement of agricultural productivity has been identified as a critical area of nanotechnology application nanotechnology for attaining the Millennium Development Goals. In light of the developments worldwide hailing nanotechnology as a technology with the potential of addressing a number of developing country needs, India has sought to promote nanotechnology applications in sectors that are likely to have a wide impact, and influence the course of future development in the country. Sectors such as health, energy and environment have received greater attention by various technology departments in the government (DST, DBT and SERC).

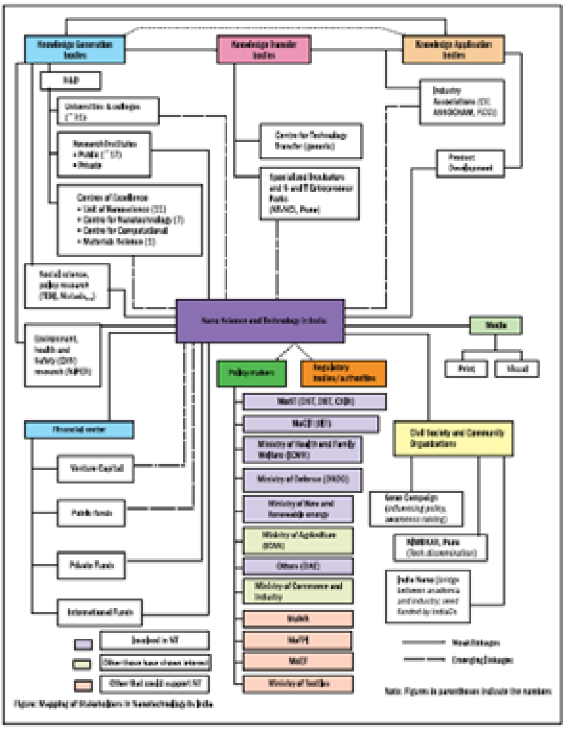

Fig 1: Map of stakeholders in Nanotechnology in India

APPLICATION OF NANO TECHNOLOGY IN BUILDING MATERIALS

Many disciplines of civil engineering including design and construction processes can be benefited from nanotechnology. For example, new structural materials with unique properties, lighter and stronger composites, fire insulator, sound absorber, low maintenance coating, water repellents, nano-clay filled polymers, self-disinfecting surfaces, UN light protector, air cleaners, nano sized sensors, ultra-thin- strong- conductive wafers, solar cells etc. to name a few. This paper presents, in brief, the areas of application of nanotechnology in civil engineering and the science & technology behind the improved performance. Further, the existing challenges that the scientists and technologists facing towards exploiting the potentiality of nanotechnology is also brought out.

NANOTECNOLOGIES FOR CONCRETE

Concrete is a macro-material strongly influenced by its nanoproperties. The addition of nano-silica (SiO_2) to cement based materials can control the degradation of the calcium-silicate hydrate 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 multiwalled nanotubes show the best improvements both in compressive strength and flexural strength compared to the reference samples.

Much of the analysis of concrete is being done at the nano-level in order to understand its structure using the various techniques developed for study at that scale such as Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and Focused Ion Beam (FIB). Silica (SiO_2) is present in conventional concrete as part of the normal mix. However, one of the advancements made by the study of concrete at the nano scale is that particle packing in concrete can be improved by using nano-silica which leads to a dignifying of the micro and nanostructure resulting in improved mechanical properties. Nano-silica addition to cement based materials can also control the degradation of the fundamental C-S-H (calcium-silicate- hydrate) reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability. Related to improved particle packing, high energy milling of ordinary Portland cement (OPC) clinker and standard sand, produces a greater particle size diminution with respect to conventional OPC and, as a result, the compressive strength of the refined material is also 4 to 6 times higher (at different ages). Another type of nano particle added to concrete to improve its properties is titanium dioxide (TiO_2).TiO_2 is a white pigment and can be used as an excellent reflective coating. It is incorporated, as nano particles and it is added to paints, cements and windows for its sterilizing properties since TiO_2 breaks down organic pollutants, volatile organic compounds and bacterial membranes through powerful catalytic reactions. It can therefore reduce airborne pollutants when applied to outdoor surfaces. Additionally, it is hydrophilic and therefore gives self-cleaning properties to surfaces to which it is applied. The process by which this occurs is that 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, already used in projects around the world, has a white colour that retains its whiteness very effectively unlike the stained buildings of the material's pioneering past.

It is evident from the below fig. that the SCCNFC (self-consolidating carbon Nano fiber concrete) column failed at higher loads and with larger deflection than the SCRC (steel confined reinforced concrete) column. Additionally, the SCCNFC column was much stiffer than the SCRC column and exhibited higher energy dissipation. SCCNFC can also be used as a type of self-Structural Health Monitoring system.

Finally, fiber wrapping of concrete is quite common today for increasing the strength of pre- existing concrete structural elements. Advancement in the procedure involves the use of a **fiber sheet (matrix)** containing nano-silica particles and hardeners. These nanoparticles penetrate and close small cracks on the concrete surface and, in strengthening applications, the matrices form a strong bond between the surface of the concrete and the fiber reinforcement. In the strengthening process pre-cut carbon tows (fibres) and sheets impregnated with the matrix are placed on the prepared concrete surface and bonded using grooved rollers. The ability of the samples to sustain load after cracking is greatly improved by the carbon tows and both the matrix and the interface are durable under wetting and drying and scaling (scraping) conditions. Additionally, there is no decrease in the maximum load capacity after repeated cycles of wetting and drying or scaling.

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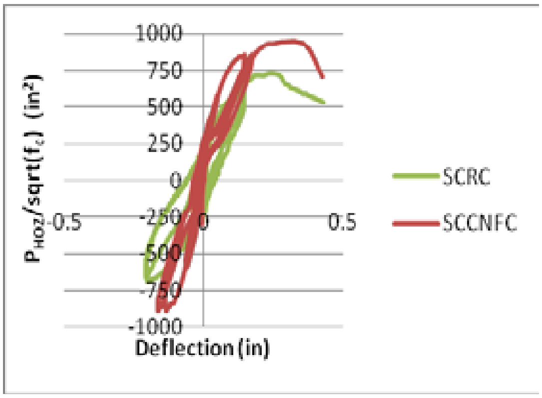

Fig 2. Horizontal forces vs Displacement curves

NANOTECNOLOGY AND STEEL

Steel has been widely available since the second industrial revolution in the late part of the 19th and early part of the 20th Century and has played a major part in the construction industry since that time. Fatigue is a significant issue that can lead to the structural failure of steel subject to cyclic loading, such as in bridges or towers. This can happen at stresses significantly lower than the yield stress of the material and lead to a significant shortening of useful life of the structure. The current design philosophy entails one or more of three limiting measures: a design based on a dramatic reduction in the allowable stress, a shortened allowable service life or the need for a regular inspection regime. **Stress risers** are responsible for initiating cracks from which fatigue failure results and research has shown that the addition of **copper nanoparticles** reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking. Advancements in this technology would lead to increased safety, less need for monitoring and more efficient materials used in construction prone to fatigue issues. Welds and the Heat Affected Zone (HAZ) adjacent to welds can be brittle and fail without warning when subjected to sudden dynamic loading, and weld toughness is a significant issue especially in zones of high seismic activity. Weld and HAZ failures led to the re-evaluation of welded structural joints in the aftermath of the 1994 Northridge earthquake in the Los Angeles area and current design philosophies include selective weakening of structures to produce controlled deformation away from brittle welded joints or the deliberate over-sizing of structures to keep all stresses low. Research currently under way, however, has shown that the addition of nanoparticles of magnesium and calcium makes the HAZ grains finer (about 1/5the size of conventional material) in plate steel and this leads to an increase in weld toughness. This is sustainability as well as a safety issue, as an increase in toughness at welded joints would result in a smaller resource requirement because less material is required in order to keep stresses within allowable limits.

Two relatively new products that are available today are **SandvikNanoflex**and **MMFX2** steel .Both are corrosion resistant, but have different mechanical properties and are the result of different applications of nano technology. Traditionally, the tradeoff between steel strength and ductility is a significant issue for steel; the forces in modern construction require high strength, whereas safety (especially in seismic areas) and stress redistribution require high ductility. This has led to the use of low strength ductile material in larger sizes than would otherwise be possible with high strength brittle material and consequently it is an issue of sustainability and efficient use of resources. **SandvikNanoflex**has both the desirable qualities of a high Young's Modulus and high strength and it is also resistant to corrosion due to the presence of very hard nanometre-sized particles in the steel matrix. It effectively matches high strength with exceptional formability and currently it is being used in the production of parts as diverse as medical instruments and bicycle components, however, its applications are growing. The use of stainless steel reinforcement in concrete structures has normally been limited to high risk environments as its use is cost prohibitive. However, MMFX2 steel, while having the mechanical properties of conventional steel, has a modified nano-structure that makes it corrosion resistant and it is an alternative to conventional stainless steel, but at a lower cost.

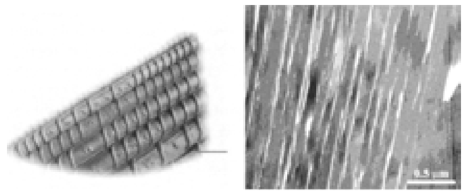

Fig 3. Nanostructure modified steel reinforcement

NANOTECNOLOGY AND WOOD

Carbon nanotubes are a new discovery, whereas wood is an ancient material which has been used since the dawn of civilization. However, perhaps not surprisingly given nature's evolutionary process, wood is also composed of nanotubes or **"nanofibrils"; namely**, **lignocellulosic (woody tissue)** elements which are twice as strong as nanofibrils would lead to a new paradigm in sustainable construction as both the production and use would be part of a renewable cycle. Some developers have speculated that building functionality onto lignocellulosic surfaces at the nano scale could open new opportunities for such things as self-sterilizing surfaces, internal self-repair, and electronic lignocellulosic devices. Due to its natural origins, wood is leading the way in cross-disciplinary research and modelling techniques. Firstly, BASF have developed a highly water repellent coating based on the actions of the lotus leaf as a result of the incorporation of silica and alumina nano particles and hydrophobic polymers. And, secondly, mechanical studies of bones have been adapted to model wood, for instance in the drying process.

NANOTECHNOLOGY AND COATINGS

The coatings incorporate certain Nano particles or Nano layers have been developed for certain purpose including: protective or anti-corrosion coatings for components; self-cleaning, thermal control, energy saving, anti-reflection coatings for glass/ windows; easy-to-clean, antibacterial coatings for work surfaces; and more durable paints and anti-graffiti coating for buildings and structures. For example: Self-cleaning windows have been developed and marketed by Pilkington, St. Gobain Co., and others. This coating works in two stages. First, using a 'photo catalytic' process, nanosized TiO2 particles in the coating react with ultra-violet rays from natural daylight to break down and disintegrate organic dirt. Secondly, the surface coating is hydrophilic, which lets rainwater spread evenly over the surface and 'sheet' down the glass to wash the dirt away. It can therefore reduce airborne pollutants when applied to outdoor surfaces. Coating of 7000 m2 of road surface with such a material in Milan in 2002 has led to a 60% reduction in nitrogen oxides concentration at street level . Research has also demonstrated that bimetallic Nano particles, such as Fe/Pd, Fe/Ag, or Zn/Pd, can serve as potent reductants and catalysts for a large variety of environmental contaminants.

Another approach to create self-cleaning surface coating has been the development of 'Lotus Spray' products by BASF, based on ideas of replicating the spotless lotus leaves by incorporating silica and alumina nanoparticles and hydrophobic polymers. The product offers 20 times more water-repellent property than a smooth, wax coating. With its applications in the construction industry, the company aims to develop a product that will retain its lotus effect even after an abrasion with sandpaper.

Special coatings can also make the applied surface both hydrophobic and oleophobic at the same time. These could be used for anti-graffiti surfaces, carpets and protective clothing etc. Researchers in Mexico has successfully developed a new type of anti-graffiti paint DELETUM, by functionalizing nanoparticles and polymers to form a coating repellent to water and oil at the same time, as shown in below fig.3

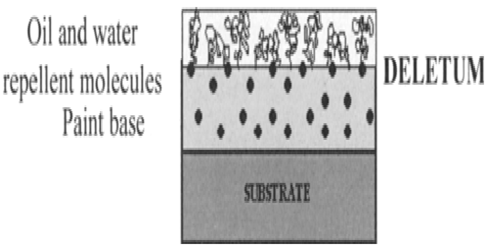

Fig 4. Stratigraphy of Deletum anti-graffiti coating

As a result, the coated surface is non-stick or very easy to clean, and able to withstand repeated graffiti attacks.

Furthermorenano structured coatings can be used to selectively reflect and transmit light in different wavebands. Research is focusing on smart and responsive materials able to sense and adapt to surroundings and change their appearance, such as whose color changes as a function of temperature, and cladding which responds to heat and light to minimize energy use in buildings.

NANOTECHNOLOGY AND GLASS

Fire-protective glass is another application of nanotechnology. This is achieved by using a clear in tumescent layer sandwiched between glass panels (an interlayer) formed of fumed silica (SiO_2) nano particles which turns into a rigid and opaque fire shield when heated. The electro chromic coatings are being developed that react to changes in applied voltage by using a tungsten oxide layer; thereby becoming more opaque at the touch of a button. Because of the hydrophobic properties of TiO_2, it can be applied in antifogging coatings or in self-cleaning windows. Nano-TiO_2 coatings can also be applied to building exteriors to prevent sticking of pollutants, and thus reduce a facility's maintenance costs.

NANOTECHNOLOGY AND NANOSENSORS

Nanotechnology enabled sensors/devices which exhibit 'self-sensing' and 'self-actuating' capability also offer great potential for developing smart materials and structures. The device used for air bags in cars is such an example. Nano and Micro electrical mechanical systems (NEMS & MEMS) sensors range from 10^{-9} m to 10^{-5} m which could be embedded into the structure during the construction process. They can monitor and/or control the environment conditions (e.g. temperature, moisture, smoke, noise, etc.) and the materials/structure performance (e.g. stress, strain, vibration, cracking, corrosion etc.) during the structure's life. Smart aggregate, a low cost piezoceramic-based multi-functional device, has been applied to monitor early age concrete properties such as moisture, temperature, relative humidity and early age strength development. Also it can provide an early indication before a failure of the structure occurs. Thus the sensors are able to work as self-health monitoring system.

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

NANOTECHNOLOGY AND SELF HEALING CONCRETE

Experimentation is also underway on self-healing concrete. When self-healing concrete cracks, embedded microcapsules rupture and release a healing agent into the damaged region through capillary action. The released healing agent contacts an embedded catalyst, polymerizing to bond the crack face closed. In fracture tests, self-healed composites recovered as much as 75 percent of their original strength. They could increase the life of structural components by as much as two or three times. When cracks form in this self-healing concrete, they rupture microcapsules, releasing a healing agent which then contacts a catalyst, triggering polymerization that bonds the crack closed.

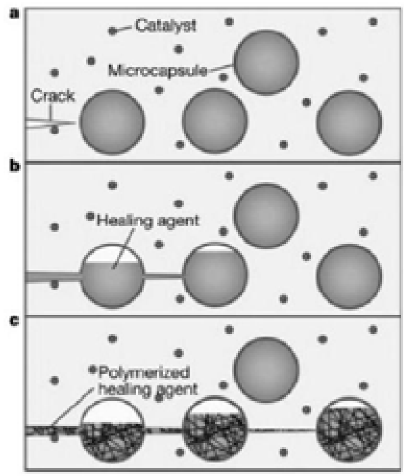

Fig 5. Mechanism of self-healing concrete

STRENGTH COMPARISONS

The compressive strength results of series C0 and N mixtures are shown in Comparison of the results from the 7, 28 and 90 days samples shows that the compressive strength increases with nano-ZrO_2 particles chemical up to 1.0% replacement (N2) and then it decreases, although the results of 2.0% replacement (N4) is still higher than those of the plain cement concrete (C0). It was shown that the use of 2.0% nano-ZrO_2 particles decreases the compressive strength to a value which is near to the control concrete. This may be due to the fact that the quantity of nano-ZrO_2 particles (pozzolan) present in the mix is higher than the amount required to combine with the liberated lime during the process of hydration thus leading to excess silica leaching out and causing a deficiency in strength as it replaces part of the cementite's material but does not contribute to strength. Also, it may be due to the defects generated in dispersion of nanoparticles that causes weak zones.

Table 1:

SAMPLE DESIGNATION	NANO ZRO2 PARTICLE (%)	COMPRESSIVE STRENGTH(MPA)		
		7 DAYS	28 DAYS	91 DAYS
C0	0	27.3	36.8	42.3
N1	0.5	31.6	42.7	46.5
N2	1.0	33.1	43.6	48.1
N3	1.5	32.2	42.9	47.1
N4	2.0	28.5	39.7	44.3

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NANO TECHNOLOGY AND GREEN BUILDING

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

NANOTECHNOLOGIES FOR FIRE PROTECTION

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

NANOTECHNOLOGIES FOR THERMAL INSULATION

Micro- and nanoporous aerogel materials are appropriate for being core materials of vacuum insulation panels but they are sensitive to moisture. As 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.

IMPACTS OF NANOTECHNOLOGY ON CONSTRUCTION:

MERITS:-

1) Compared with conventional TiO2, TiO2 at the nano-scale experiences a 500% increase in surface area and a 400% decrease in opacity. Current nano-TiO2 production levels have reached approximately 4 million metric tons at a price of approximately $45/kg to $50/kg vs. $2.5/kg for conventional TiO2.
2) The CNT market worldwide is expected to grow from $51 million in 2006 to more than $800 million by 2011 (BCC Research 2008).
3) Nano-modified concrete cuts down construction schedules while reducing labor-intensive (and expensive) tasks. Also it can reduce the cost of repair and maintenance.
4) The paint and coatings industry consists of approximately annual sales of $20 billion (Baer et al. 2003). Nano-alumina and titanium have a four- to six-fold increase in wear resistance, with doubled toughness and bond strength (Gell 2002).
5) The potential global market of nanocomposites is estimated at $340 billion for the next two decades (Roco and Bainbridge 2001).

DEMERITS

1) Nano particles being very small in size have the potential to negatively affect the respiratory and digestive tracks and the skin or eye surface thus exposes workers to hazards.
2) Since nanotechnology-related industries are relatively new, the type of worker who is employed in construction research and development or even some field applications must have an interdisciplinary background.
3) New policies in the context of nanotechnology will require co-operation between various levels of government, R&D agencies, manufacturers, and other industries.
4) Small production volumes and high cost remain the main barriers to the use of Nanotechnology (The Royal Society 2004).

CONCLUSION

Nano materials and nanotechnologies have attracted considerable scientific interest due to the new potential uses of particles in nanometer scale and, consequently, large amount of funds and effort have being utilized. Even though construction materials may constitute only a small part of this overall effort, it could pay enormous rewards in the areas of technological breakthroughs and economic benefits.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 nanomaterial in construction is viable in four major directions of development: structural concrete; real time structural monitoring; coatings and paintings; thermal insulations.

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