E-ISSN: 2278–179X

JECET; September-November, 2012; Vol.1.No.3, 263-270.

Journal of Environmental Science, Computer Science and Engineering & Technology

Available online at www.jecet.org

Engineering & Technology

Research Article

A Prudent Approach to Civil Engineering: Nano Materials

Vipul Thakur and Dheeraj Mandloi

Department of Civil Engineering, Institute of Engineering and Technology,
Devi Ahilya University, Indore (M.P.), INDIA

Received: 14 August 2012**; Revised:** 30 August 2012**; Accepted:** 10 September 2012

Abstract: Use of very small particles of material either by themselves or by their manipulation to create new large scale materials is the pith of nano technology. The properties of the material actually become affected, the size of the particles is very important at the length scale of nanometre, 10^{-9}m. The precise size at which these changes are evinced varies between materials, but is usually 100 mm or less. Nanotechnology is an extension of the science and technologies that have already been in development for many years and it is the logical concatenation of the work that has been done to examine the nature of world at a very minuscule scale. A nanometre is a billionth of a metre. Recent developments in the study and manipulation of materials and processes at the nanoscale offer the alluring anticipation of producing new macro materials, properties and products. An inevitable beneficiary of this nanotechnology is construction commercial enterprise; in fact it is already in the fields of concrete, steel and glass. Concrete has been made more durable, stronger and more easily placed, steel is much more rugged and glass has been delineated self-cleaning properties. Increased strength and durability are the major attributes of construction materials these days among the efficient usage of resources. This is achieved both prior to the construction process by a reduction in pollution during the production of materials (e.g. cement) and also in service, through efficient use of energy due to advancements in insulation. Many other effects of nanotechnology on the industry are also discussed in the paper. Two nano-sized particles that stand out in their application to construction materials are titanium dioxide (TiO_2); and carbon nanotubes (CNT's). The former is being used for its ability to break down dirt or pollution and then allow it to be washed off by rain water on everything from concrete to glass and the latter is being used to strengthen and overseer concrete. CNT's though, have many more properties, apart from exceptional strength, that are being researched in computing, aerospace and other areas as well. Cost and the relatively small number of practical applications, for now, hold back much of the prospects for nanotechnology. Materials though, as mentioned above, are construction's core business and the prospects for more changes are significant in the not too distant future, in fact, the researchers surveyed predicted that many advances would arrive within five years. In order to capitalize on the effects of nanotechnology on the business, increased interdisciplinary working between researchers and communication between those researchers and industry is entailed. If nothing else, changes outside the immediate scope of construction (e.g. demographic or environmental) will drive the need for innovation in the industry.

Keyword: Nano materials, Carbon nanotubes, Nano composite.

1. INTRODUCTION

Nanotechnology is the use of very small pieces of material by themselves or their manipulation to create new large scale materials. At the nanoscale (anything from one hundred or more down to a few nanometres, or 10^{-9}m) material properties are altered from that of larger scales. It is these "nano-effects", however, that ultimately determine all the properties that we are familiar with at our macro-scale. The structure of the fundamental calcium-silicate-hydrate (C-S-H) gel which is responsible for the mechanical and physical properties of cement pastes, including shrinkage, creep, porosity, permeability and elasticity, can be modified to obtain better durability. Globally, $1m^3$ of concrete per year is produced for each person on earth. The scope of nanotechnology in construction[1-5] is vast and an attempt has been made to shift through the work being done and the future being forecast to represent a readable summary of where nanotechnology stands today in relation to the effects it may have on the industry.

2. EXPERIMENTS DESIGN AND SETUP

2.1 Nanotechnology in Construction: There are several finished raw materials, which we see, being used in the construction industry like Concrete, Steel, Self cleaning Glass, Paints etc. Nanotechnology helps in improving the material's bulk properties. It develops ability to control or manipulate materials at the atomic scale. It is easy to obtain thinner final products with faster setting time. It is also cost effective and has lowered levels of environmental contamination.

- Concrete is made stronger, more durable and more easily placed.
- Steel is developed such that its durability, strength and lifespan have increased. It is made much tougher.
- Self cleaning glass is developed.
- Paints are being made more insulating and water repelling.

2.2 Nano Materials: ***Nano particle*** – It is defined as a particle with at least one dimension less than 200 nm.

Nano composite – It is produced by adding Nano particle to a bulk material in order to improve the bulk material's properties.

2.2.1 What Is Carbon Nanotube (CNT): Carbon nanotube (CNT) is a form of carbon. It is cylindrical in shape, and its name comes from the nanometre diameter. It can be several millimetres in length. The production cost of nanotubes is high and the price ranges from 1200 INR to 60,000 INR per gram depending on quality. Multi-walled tubes slide telescopically without resistance and they can be ballistically electrically conducting (with no resistance) or semi-conducting depending on the exact structure. Thermal conduction is also very high along the tube axis. CNT tubes are known to have 5 times the Young's Modulus and 8 times (theoretically 100 times) the strength of steel whilst being $1/6^{th}$ density. These are the subject of important areas of research in nanotechnology.

2.2.2 Tubestructure: Carbon nanotubes can be visualized as a modified form of graphite. A CNT can be thought of as sheets of graphite that have been rolled up into a tube structure. CNT can be single walled nanotubes (SWNT), or multi walled (MWNT), similar in appearance to a number of sheets rolled together.

2.3. Applications of Carbon Nanotubes in the Construction Industry: The first application is likely to be in CNT composite materials. CNT are excellent reinforcing materials because of extremely high strength, toughness and aspect ratios. Polymer, cement and glass are all potential candidates for CNT matrix materials.

Glass reinforced with CNT is of interest due to the possibility that tubes may be able to provide reinforcement without interfering with light transmittance. This can be used in ropes for applications such as suspension bridges, where CNT strengths and moduli of elasticity would allow for the design of significantly longer spans than existing technology makes possible. Carbon nanotubes have also been discussed as materials for the construction of space based structures e.g., space elevators. These cable systems have the theoretical capability of reaching from the earth's surface to far beyond geosynchronous orbit.

2.4. Cement Systems: Concrete is the single most important construction material. OPC is formed by grinding amorphous masses of cement clinker and gypsum into powder. The primary constituents of the clinker are a series of oxides, including tricalcium silicate (C_3S in cement chemistry notation), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetra calcium aluminoferrite (C_4AF). Hydrated cement is a brittle material that is much stronger in compression than intension. Indirect measurements of tensile strength give values below 4 MPa, while the compressive strengths of the same concretes are more than order of magnitude higher in value. Cement itself has a complex, nanoscale structure. Some of the properties that affect the strength of cement are expected to act at the nanoscale.

Improved mechanical performance and for developing better performance is done by the addition of the nanoscale reinforcing materials, which might range from small spheres that would only act to interrupt cracking to nano-fibres or rods.

2.5. Carbon Nano Tubes in Concrete: The addition of small amounts (1% wt.) of CNT's can improve the mechanical properties of samples consisting of the main Portland cement phase and water. Oxidized multi-walled Nano tubes (MWNT's) show the best improvements both in compressive strength

(+25N/mm2) and flexural strength (+8N/mm2) compared to the samples without the reinforcement. It is theorized the high defect concentration on the surface of the oxidized MWNTs could lead to a better linkage between the nano structures and the binder thus improving the mechanical properties of the composite.

2.6. Titanium Dioxide: Titanium dioxide is a widely used white pigment because of its brightness. It can also oxidize oxygen or organic materials, therefore, it is added to paints, cements, windows, tiles, or other products for sterilizing, deodorizing and anti-fouling properties. Additionally, as TiO_2 is exposed to UV light, it becomes increasingly hydrophilic (attractive to water), thus it can be used for anti-fogging coatings or self cleaning windows. Rain water is attracted to the surface and forms sheets which collect the pollutants and dirt particles previously broken down and washes them off.

2.7. Nanotechnology in Titanium Oxide: It is incorporated, as nano particles, in sun-block to block UV light 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.

2.8. Concrete: Concrete is a mixture of cement, sand (fine aggregate), coarse aggregate and water. The mechanical behaviour of concrete materials depends on phenomenon’s that occur on a micro and a nano scale.

2.9. Nano Technology in Concrete: “A concrete made with Portland Cement particles that are less than 500 Nano-meters as the cementing agent”. Concrete is, after all, a macro-material strongly influenced by its nano properties. At the basic science level, much analysis of concrete is being done at the nano-level in order to understand its structure using the various techniques developed for study. Silica (SiO2) is present in conventional concrete as part of the normal mix. Particle packing in concrete can be improved by using nano-silica which leads to densifying of the micro and nanostructure resulting in improved mechanical properties. The compressive strength of the refined material is also 3 to 6 times higher (at different ages). CO_2 emissions from the global cement industry are significant and they are increasing. Global cement production is currently around 1.6 billion tonnes/year, and through the calcinations of limestone to produce calcium oxide and carbon dioxide, approximately 0.97 tonnes of CO_2 is produced for each ton of clinker produced. Around 900kg of clinker is used in each 1000kg of cement produced so the global cement industry produces around 1.4 tonnes of CO_2 each year. This represents about 6% of the total worldwide man-made CO_2 production.

2.9.1. Self Compacting Concrete (SCC): Self Compacting Concrete does not need vibration in order to level off and achieve consolidation. This represents a significant advance in the reduction of the energy needed to build concrete structures. In addition SCC can offer benefits of up to 50% in labour costs, due to it being poured up to 80% faster and having reduced wear and tear on formwork. The material behaves like a thick fluid and is made possible by the use of polycarboxylates. SCC mixes, which contain a high content of fine particles, need a very effective dispersing system in order to be fluid and workable overtime at low water/cement ratio (high W/C ratios would lead to risk of segregation) and only polycarboxylates can meet these requirements. A fibre sheet (matrix) is used, containing nano-silica particles and hardeners. These nano-particles 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. There is no decrease in the maximum load capacity after repeated cycles of wetting and drying or scaling.

2.10. Nano Silica: Particle packing in concrete can be improved by using nano-silica which leads to densifying 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 3 to 6 times higher. Average size of Portland cement particle is about 50 microns. In thinner final products and faster setting time, micro cement with a maximum particle size of about 5 microns is being used. Hydration tests indicated the Nano-cement had a more rapid hydration rate than Portland cement.

2.11. Fly Ash: Fly ash not only improves concrete durability, strength and importantly for sustainability, reduces the requirement for cement, however, the curing process of concrete is slowed by the addition of fly ash and early stage strength is also low in comparison to normal concrete. With the addition of SiO2, nano-particles part of the cement is replaced but the density and strength of the fly-ash concrete improves particularly in the early stages. Research into hematite (Fe_2O_3) nano-particles added to concrete has shown that they also increase strength as well as offering the benefit of monitoring stress levels through the measurement of section electrical resistance.

2.12 Nano Technology in Steel: 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. Addition of copper nano-particles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking.

Steel: High strength steel cables, as well as being used in car tires, are used in bridge construction and in pre-cast concrete tensioning and a stronger cable material would reduce the costs and period of construction, especially in suspension bridges as the cables run from end to end of the span. High rise structures require high strength joints and this in turn leads to the need for high strength bolts. When the tensile strength of tempered marten site steel exceeds 1,200 MPa even a very small amount of hydrogen embrittles the grain boundaries and the steel material may fail during use. This phenomenon, which is known as delayed fracture, has hindered the further strengthening of steel bolts and their highest strength has long been limited to somewhere around 1,000 to 1,200 MPa. Research work on vanadium and molybdenum nano-particles has shown that they improve the delayed fracture problems associated with high strength bolts.

Welds and the Heat Affected Zone (HAZ) adjacent to welds can be brittle and fail without warning when subjected to sudden dynamic loading. Research currently under way, however, has shown that the addition of nano-particles of *magnesium* and *calcium* makes the HAZ grains finer (about 1/5th the size of conventional material) in plate steel and this leads to an increase in weld toughness. Smaller resource requirement factor comes into play because less material is required in order to keep stresses within allowable limits.

2.12.1 What is a nano-composite: A nano-composite is produced by adding nano-particles to a bulk material in order to improve the bulk material's properties.

Two relatively new products that are available today are:-

Sandvik Nanoflex (produced by Sandvik Materials Technology); and

MMFX2 steel (produced by MMFX Steel Corp).

Both are corrosion resistant, but have different mechanical properties. Traditionally, the trade off 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.

- Sandvik Nanoflex 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. 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.

2.12.2 Temperature restriction in steel: Above 750 ^{o}F, regular steel starts to lose its structural integrity, and at 1100 ^{o}F, steel loses 50 percent of its strength. A new formula infuses steel with nanoscale copper particles, this formula could maintain structural integrity at temperatures upto 1000 ^{o}F. The new steel allows ultra-high strength to be combined with good formability, corrosion resistance and a good surface finish.

2.13 High Strength Steel Cables & High Strength Bolts: A stronger cable material would reduce the costs and period of construction, especially is suspension bridges. Sustainability is also enhanced by the use of higher cable strength as this leads to a more efficient use of materials. High rise structures require high strength joints and this in turn leads to need for high strength bolts. The capacity of high strength bolts is realized generally through quenching and tempering and the microstructures of such products consist of tempered martensite. When the tensile strength of tempered martensite steel exceeds 1200 MPa even a very small amount of hydrogen embrittles the grain boundaries and the steel material may fail during use.

Vanadium and molybdenum. Nano-particle has shown that they improve the delayed fracture problems associated with high strength bolts, improving the steel micro-structure.

2.14 Nanotechnology and Glass (Self Cleaning): ***Titanium dioxide (TiO_2)*** is used in nano-particle form to coat glazing since it has sterilizing and anti-fouling properties. The particles catalyze powerful reactions which breakdown organic pollutants, volatile organic compounds and bacterial membranes. In addition, TiO_2 is hydrophilic and this attraction to water forms sheets out of rain drops which then wash off the dirt particles broken down in the previous process.

Another strategy, that produces a similar outcome by a different process, involves photo chromic technologies which are being studied to react to changes in light intensity by increasing absorption. And finally, 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.

2.15 Nanotechnology and Coatings: Much of the work involves Chemical Vapor Deposition (CVD), Dip, Meniscus, Spray and Plasma Coating in order to produce a layer which is bound to the base material to produce a surface of the desired protective or functional properties. Nanotechnology is being applied to paints and insulating properties, produced by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction, are currently available. This type of paint is used, at present, for corrosion protection under insulation. Nano-particle based systems can provide better adhesion and transparency than conventional techniques.

2.16 Fire and Heat Protection: Fire-protective glass is achieved by using a clear intumescent layer sandwiched between glasses panels (an interlayer) formed of fumed silica (SiO_2). Nano-particle which turns into a rigid and opaque fire shield when heated. For heat protection thin film coatings are being developed which are spectrally sensitive surface applications for window glass and filter out unwanted infrared frequencies of light (which heat up a room) and reduce the heat gain in buildings, however, these are effectively a passive solution. As an active solution, thermo chromic technologies are being studied which react to temperature and provide insulation to give protection from heating whilst maintaining adequate lighting. Fire resistance of steel structures is often provided by a coating produced by a spray-on cementitious process. Polypropylene fibres also are being considered as a method of increasing fire resistance.

2.17 Nanotechnology in Sustainability and Environment: Sustainability is defined as “the ability to provide for the needs of the world's current population without damaging the ability of future generations to provide for themselves”. Another key aspect of sustainability is the efficient use of energy. World over almost 40% of total energy produced is consumed by buildings. Micro and nonporous aero gel materials are very good candidates for being core materials of vacuum insulation panels but they are sensitive to moisture. As a possible remedy, work by Aspen Aero gels has produced an ultra-thin wall insulation which uses a nano porous aero gel structure which is hydrophobic and repels water so it is mould free. Another intriguing application of aero gels is silica based products for transparent insulation, which leads to the possibility of super-insulating windows.

2.18 What is an Aero gel?: A gel precursor is a chemical or mixture of chemicals that can be activated towards the formation of small (nano-sized) particles suspended in a liquid (a colloid). A wet gel forms when a solution of these dispersed nano-particle colloids (also called “sols”) are induced to form a semi-solid form via condensation. The solid in the wet gel phase can define a high surface area network of nano-diameter pores that confine the liquid within the structure. An aero gel is directly derived from a wet gel in a process that replaces the entrained liquid with air. The highly porous nature of the resulting aero gel structure provides a huge amount of surface area per unit weight. The percentage of open space within an aero gel structure is about 94%, giving a tortuous path for heat, and this leads to it having the lowest thermal conductivity value of any solid.

3. CONCLUSION

“At this moment the main limitation is the high costs of nanotechnology. Also concerns with the environmental and health effects”. There are three main issues that might prevent the widespread use of the nanotechnology (1) Lack of vision to identify those aspects that could be changed through its use, (2) Lack of skilled personnel and (3) Level of investment. Essentially, there is a lack of knowledge in material physics and chemistry in the curriculum of civil engineers. Nanotechnology in concrete like materials seems to be dedicated rather to testing, observing the nature, than to modifying it.

Whilst the ability to image individual atoms and manipulate them will excite the few, the real focus now and the near future is rather more prosaic.

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*Correspondence Author: **Dheeraj Mandloi;** Department of Civil Engineering, Institute of Engineering and Technology, Devi Ahilya University, Indore (M.P.), INDIA