A review of current and future developments in the application of Nanotechnology to construction materials

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Abstract

Nanotechnology is one of the most recent multidisciplinary areas of interest for materials scientists and engineers. To construction materials engineers, nano-technology is quite new and possible applications to civil engineering materials are still under development. This paper reviews the state of the field of nanotechnology in concrete. A broad overview of the potential application of various nanotechnology developments in the construction engineering field is discussed, and the potential for further basic research that may lead to improved systems is evaluated. Recent progress in nano-engineering and nano-modification of cement-based materials is presented. Recommendations are made for future studies.

Keywords: Nanomaterials, Construction, Cement, Concrete, Civil Engineering

1. INRODUCTION

The field of Nanotechnology is a field that is based on phenomena at the atomic and molecular scales and are used to provide materials and structures that perform tasks that are not generally possible using the materials in their typical macroscopic scale.
Nanotechnology is concerned with objects between 1 and 100 nm in size (Nanometer),
(1 Nanometer – 1 x 10^{-9}m). It is a study based on the production and application of physical, chemical and biological products at scales ranging from a few nanometers to submicron dimensions. It also deals with the evolution and integration of nanostructures into larger entities.

This development has been helped by the evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry which are taking research on nanotechnology to a new height. Not surprisingly, it is observed that expenditure on nanotechnology research is significant internationally. Research is in this area, however, is slow in taking off in developing countries; it is moving forward in developed countries motivated by immediate profitable return generated by high value commercial products [1].

Drexler [2] defines nanotechnology as “the control of matter based on molecule-by-molecule control of products and by-products through high-precision systems as well as the products and processes of molecular manufacturing, including molecular machinery.”

Two approaches to the achievement of nanoscale material may be defined:
Bottom up approach in which organic and inorganic structures are constructed atom by atom or molecule by molecule to form a larger system. This can be illustrated in nature through the mechanical performance of biomaterials, such as bones or shells which derives from the presence of nano-crystals of calcium compounds.

A more popular approach in manufacturing is the top–down approach in which bulk materials are broken down mechanically to nanoparticles. The dimensions of a material are reduced from macro-size to nano-size. This reduction in size introduces new properties and behaviour in the material which is explored by engineers and scientists. Changes occur in the electronic conductivity, optical absorption, chemical reactivity and mechanical properties of the material as well as increased surface area. The increased surface area imparts additional surface energy and surface morphology.

2. NANOTECHNOLOGY IN CONSTRUCTION

Construction Industry is one of the most booming industries in the world. The application of nanotechnology to construction processes and materials have generated products with many unique characteristics. The next phase in construction is where inputs are less and lighter, they are smooth and stronger; they are cost effective, cleaner and sustainable. The move towards more sophistication can be achieved with the help of emerging technologies like nanotechnology. These characteristics can significantly improve many defiencies in current construction systems, and may also change the requirement and organization of construction process. Some of the improvements in construction materials and systems include:

• Lighter and stronger structural composites
• Low maintenance coating
• Improving pipe joining materials and techniques.
• Better properties of cementitious materials
• Reducing the thermal transfer rate of fire retardant and insulation
• Increasing the sound absorption of acoustic absorber

The sheer size and scope of the construction industry means that the accompanying economic impact of the application of nanotechnology will be huge. In order to capitalize on the effects of nanotechnology in the construction industry, however, much more funding for construction related research, increased interdisciplinary working between researchers and communication between researchers and industry is needed.

3. APPLICATION OF NANOTECHNOLOGY IN CONCRETE

Concrete is one of the most commonly and widely used construction materials. The development of experimental techniques based on nanotechnology make it possible to study the properties of cementitious materials at micro and nano scales. Much work has been done on the hydration process of cement, alkali-silicate reaction (ASR) on concrete, and on the use of supplementary cementitious materials [3]. The interests in concrete as a material come from the following factors:

- Concrete is by far the largest construction material by volume
- 60% of global industrial waste is from the construction and demolition of buildings
- 60% of electrical use in developed nations is by buildings
- 40% of total energy consumed is by buildings

Figure 1 illustrates the relative volume of different construction materials used in construction.

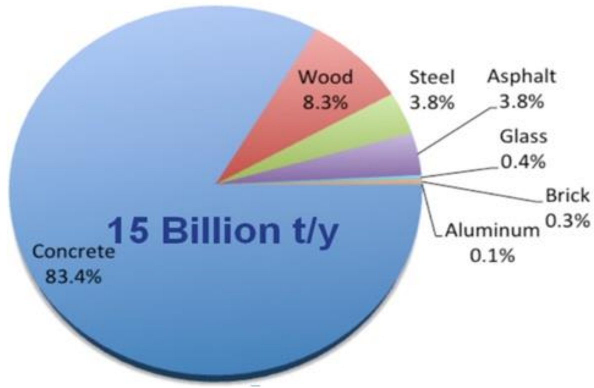

Figure 1: Relative volume of different construction materials used in construction.

Concrete is traditionally defined as a mixture of cement, Aggregate (fine and coarse) and water. Modern concrete technology has shifted away from the traditional three component concrete to a five component concrete by the inclusion of chemical additives as well as supplementary cementitious materials (SCM). The components of concrete are illustrated in Figure 2. This has paved the way for the use of nano-scale materials in concrete as SCM.

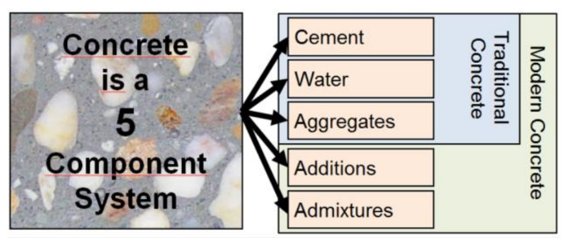

Figure 2: Components of concrete

There are environmental concerns associated with cement and concrete production. Cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, greenhouse gases, noise and vibration when operating machinery and during blasting in quarries, and damage to countryside from quarrying. Due to the large quantities of fuel used during manufacture and the release of carbon dioxide from the raw materials, cement production also generates more carbon emissions than any other industrial process. The production of 1 tonne of Portland cement clinker results in the release of about 850 kg of CO2 to the atmosphere. Around 5 - 7% of CO2 emission in the world is caused by the cement industry as shown in Figure 3.

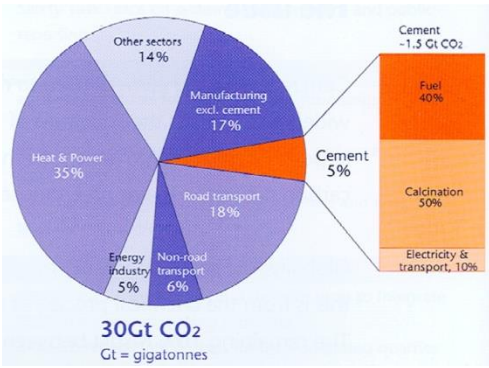

Figure 3: Breakdown of carbon emission.
Source: Green in Practice 102 - Concrete, Cement, and CO2, http://www.wbcsd.org/home.aspx

4. EFFECT OF SCM ON GREENHOUSE GAS EMISSIONS

The environmental concerns resulting from the use of cement in concrete is partly addressed by the incorporation of SCM (including nanoscale materials) in concrete. The effect of SCM in concrete is shown in Figure 4.

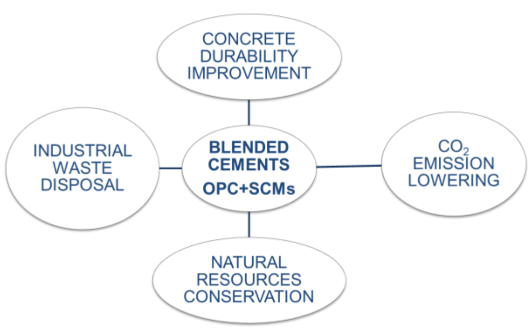

Figure 4: Effect of SCM in conrete

Typical SCMs used in concrete include: Silica fume, ground and granulated blastfurnace slag (GGBS), fly ash and metakaoline. Some of the properties due to SCM in concrete are:

- Faster hydration process
- Lower bleeding
- Higher strength
- Better workability
- Lower heat of hydration
- Better resistance to penetration of aggressive substances
- Lower price
- Reduced shrinkage

The study of cement production on greenhouse gas emissions has been presented by various authors [7]. It has been shown that by adding 30% slag to the cement, CO2 emission is decreased by 29%, and by adding 25% of flyash to cement, CO2 emission is decreased by 24.6% compared with reference cement. It is fair to say that for every 1% replacement of cement by SCM, there is a reduction of 1% in the greenhouse gas emission. This is illustrated in Figure 5.

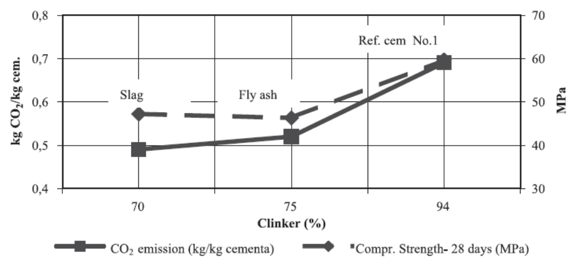

Figure 5: Effect of the use of SCM on CO2 emission. [7]

5. USE OF NANO-SCALE MATERIALS FOR OPTIMUM PACKING

Use of nano-SiO2 could significantly increase the compressive for concrete, containing large volume fly ash. This is due to the achievement of denser packing at early age and improved pore size distribution by filling the pores between large fly ash and cement particles at nanoscale. The subject of optimizing the concrete composition by selecting the right amounts of various particles has already aroused interest for more than a century. To optimize the particle packing density of concrete, the particles should be selected to fill up the voids between large particles with smaller particles and so on, in order to obtain a dense and stiff particle structure. Various researchers have proposed packing models [5, 6]. Through proper particle packing using particle sizes ranging from macro sizes to nano sizes as shown in Figure 5, can optimize the aggregate and paste for maximum density and strength. Close particle packing helps permeability and strength. The reduction in average poor size decreases the permeability of the concrete, making it more durable. This can only be achieved through good packing involving all scales of sizes. Experimental results show that water demand of a cement paste can be lowered by adding small quartz powder particle.

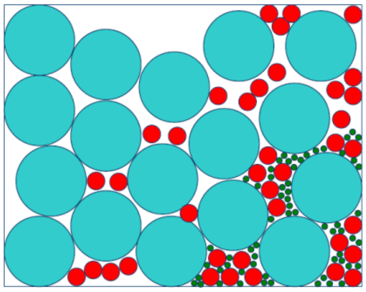

Figure 5: Packing of different sized particles

The dispersion/slurry of amorphous nanosilica is used to improve segregation resistance for self-compacting concrete [4].

6. APPLICATION IN STEEL

Due to the weakness of concrete in tensile stress, steel is used to resist tension in concrete structures and may also be used on its own as the main structural element. Steel is therefore a major construction material. Its properties, such as strength, corrosion resistance, and weld ability, are very important for design and construction. It is possible to develop new, low carbon, high performance steel (HPS). The new steel was developed with higher corrosion-resistance and weld ability by incorporating copper nanoparticles at the steel grain boundaries.

7. APPLICATION OF NANOTECHNOLOGY TO COATING

New generation paints and coatings incorporate certain nanoparticles or nanolayers which have been developed for certain purpose. It is one of the major applications of nanotechnology in construction. Nanoscale TiO_2 used in concrete is a white pigment and can be used as an excellent reflective coating. It is hydrophilic and therefore gives self-cleaning properties to surfaces to which it is applied and used as anti-graffiti treatment. For example, TiO_2 is used to coat glazing because of its sterilizing and self-cleaning properties. The TiO_2 will break down and disintegrate organic dirt through powerful catalytic reaction. Furthermore, it is hydrophilic, which allow the water to spread evenly over the surface and wash away dirt previously broken down. Other special coatings also have been developed, such as anti-graffiti, thermal control, energy sawing, anti-reflection coating.

Carbon nanotubes are a form of carbon that was first discovered in Russia in 1952 and further developed in Japan in the 1990's. They are cylindrical in shape with nanometer scale diameter. They are however expensive to produce but they can enhance the strength and durability properties of concrete. They can be single or multiple walled nanotubes as shown in Figure 6.

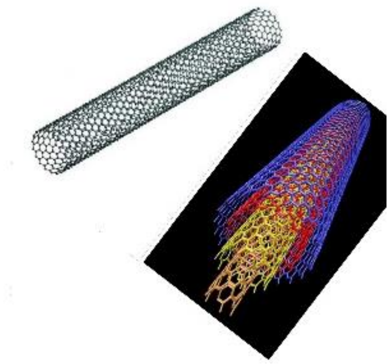

Figure 6: Types of nanotubes.

8. CONLUSIONS

Nanotechnology has created a new opportunity for material innovation. Newly developed materials are not only lighter but also stronger, more flexible, and the material has the characteristics of high sensibility, multifunction's, and intelligence.

For the design of ecological concrete a cyclic design procedure, based on particle packing
and water demand, is presented. The procedure is explained on the basis of cement paste
combined with various amounts of quartz powder added as filler.

The reduction of CO_2 emission in cement production is more achievable by using secondary raw materials (SCM) as partial replacement for cement. These materials need to be ground to nanoscale level.

The dispersion/slurry of amorphous nanosilica is used to improve segregation resistance for self-compacting concrete. It is also reported that adding a small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength of concrete.

Paints and coatings incorporating certain nanoparticles or nanolalyers have been developed as one of the major applications of nanotechnology in construction. For example, TiO2 is used to coat glazing because of its sterilizing and anti-graffiti properties.

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