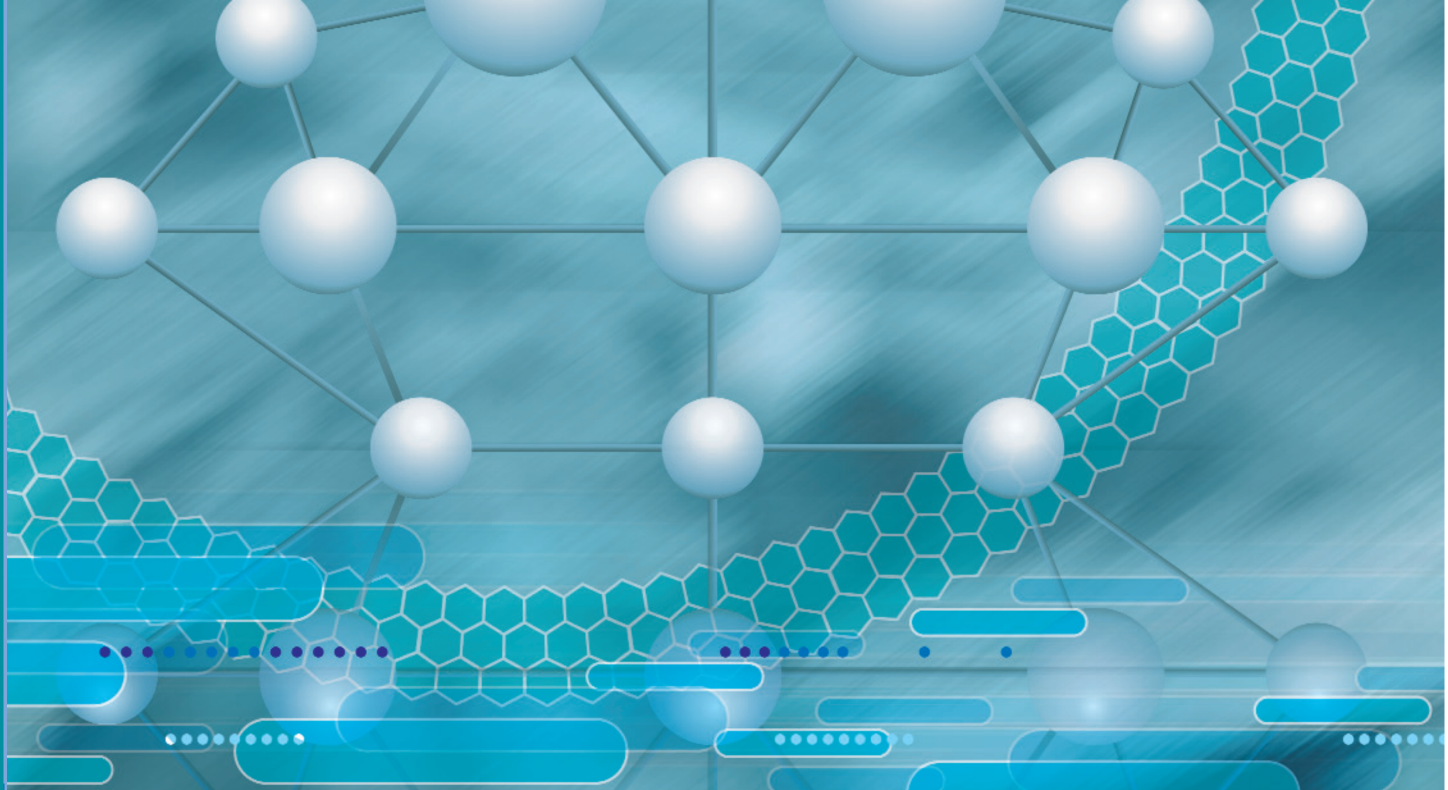

How Nanotechnology Can Change the Concrete World

Part One of a Two-Part Series

Successfully mimicking nature's bottom-up construction processes is one of the most promising directions.

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The next industrial revolution will be nanotechnology. Nanotechnology was first introduced in the famous lecture of Nobel Laureate Richard P. Feynman, "There's Plenty of Room at the Bottom," given in 1959 at the California Institute of Technology.[1]

There have been revolutionary developments in physics, chemistry and biology during the past 25 years. These developments have proved Feynman's ideas of manipulating and controlling matter at an extremely small scale, even to the level of molecules and atoms; i.e., nanoscale.[2–5]

Nanotechnology deals with the production and application of physical, chemical and biological systems at scales ranging from a few nanometers to submicron dimensions. It also deals with the integration of the resulting nanostructures into larger systems.[3] Nanotechnology also involves the investigation of matter to individual atoms.

Drexler[2] gave one of the earlier definitions of nanotechnology as "the control of matter based on molecule-by-molecule control of products and byproducts through high-precision systems as well as the products and processes of molecular manufacturing, including molecular machinery."

This definition involves the application of the bottom–up approach of molecular nanotechnology. Here, organic and inorganic structures are constructed atom-by-atom or molecule-by-molecule. However, contemporary technology continues to rely on the top–down approach. Here, bulk materials are broken down into nanoparticles by mechanical attrition and etching techniques (Fig. 1).[3–5]

According to Whatmore and Corbett,[5] the subject of nanotechnology includes "almost any materials or devices which are structured on the nanometre scale in order to perform functions or obtain characteristics which could not otherwise be achieved."

The science related to nanotechnology is new. However, nanosized devices and objects have existed on earth as long as life. The exceptional mechanical performance of biomaterials, such as bones or mollusk shells, is due to the presence of nanocrystals of calcium compounds.[6]

The nanocomposite material of the abalone shell consists of nanosized particles of calcium carbonate bound by a glue made of a carbohydrate protein mix.[7] This type of composite nanostructure leads to high strength and toughness of the shell because of interlocking of nanoblocks of calcium carbonate responsible for crack arrest and energy dissipation.

Better understanding and mimicking of the processes of bottom–up construction successfully used by nature is one of the most promising directions in nanotechnology.[3] Ancient peoples used nanosized materials in glass.[3] A later example is photography, which uses silver nanoparticles sensitive to light.

Nanotubes

The most promising contemporary developments include the synthesis of new forms of carbon: fullerene (C60) and carbon nanotubes **(Fig. 2)**. Carbon nanotubes are sometimes represented as a graphene sheet rolled into a cylinder with specific alignment of hexagonal rings and hemifullerenes attached to the tips **(Fig. 2)**.[3]

The favorable diameter of a single-walled nanotube (SWNT) is ~1.4 nm because of energetic requirements. Also, 0.4–2.5 nm diameter SWNTs have been synthesized.[3] The length of SWNTs is not restricted and can reach micron or millimeter range.

SWNTs can be classified as a single molecule with a high aspect ratio. The synthesis of SWNTs is achieved under precisely controlled conditions in the presence of a catalyst. A deviation from the production route leads to multiwall carbon nanotubes (MWNTs). MWNTs can be represented as a family of SWNTs of various diameters that are combined within a single entity. An example is the concentric-type MWNT **(Fig. 2)**.

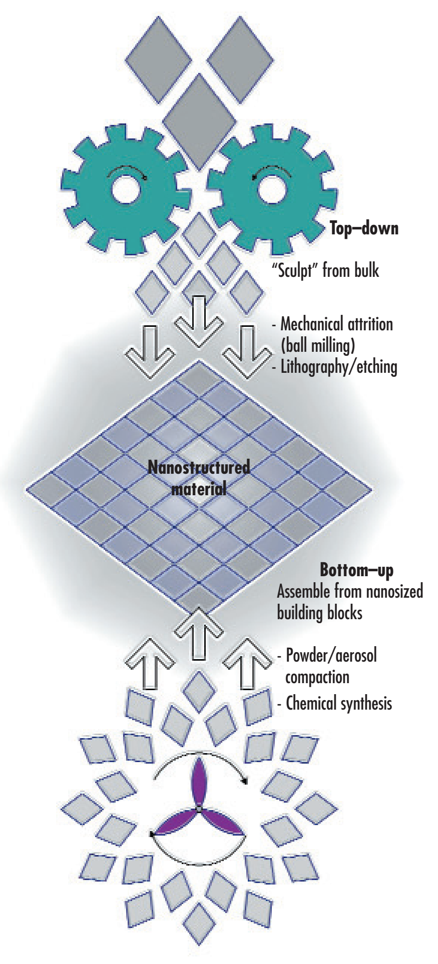

Figure 1 *Schematic of a variety of nanostructure synthesis and assembly approaches.*

Nanotube applications include nanoelectronic devices (transistors), tips for scanning probe microscopes, bio/chemical sensors, catalyst supports, gas storage/separation devices, drug delivery systems, self-healing technologies, composite materials and strength enhancements. For example, super-high-tensile-strength nanotubes have been calculated to be 20 times stronger than steel; i.e., ~45 GPa **(Fig. 3)**.

Nanotubes are an ideal reinforcing component of modern fibers. A possible application is in supporting long-span or high-rise structure cables. Such cables can be a material of choice for recently proposed space elevators.[8]

Other Nanomaterials

Three groups of nanomaterials can be specified based on their geometry/shape: quantum well (one nanosized dimension), quantum wire (two nanosized dimensions) and quantum dot (three nanosized dimensions) **(Fig. 4)**.[7] One of the principal structural units in nanotechnology is quantum dot or nanoparticle. This can be represented as a cluster of tens to thousands of atoms 1–100 nm in diameter.

When nanoparticles are created using the bottom–up approach, the size and the shape of a particle can be controlled by production conditions. These particles also can be considered as nanocrystals. The atoms within the particle are perfectly ordered, or crystalline.

When the dimensions of a material are decreased from macrosize to nanosize, significant changes in electronic conductivity, optical absorption, chemical reactivity and mechanical properties occur. With decrease in size, more atoms are located on the surface of the particle.

Nanopowders have a remarkable surface area (Fig. 5). The surface area imparts a serious change of surface energy and surface morphology. All these factors alter the basic properties and the chemical reactivity of the nanomaterials.[3,7,10] The change in properties causes improved catalytic ability,[14] tunable wavelength-sensing ability[15] and better-designed pigments and paints with self-cleaning and self-healing features.[16–18]

Nanosized particles have been used to enhance the mechanical performance of plastics and rubbers.[3,19,20] They make cutting tools harder and ceramic materials more ductile.[9,10,21,22] For example, ductile behavior has been reported for nanophase ceramics, such as titania and alumina, processed by consolidation of ceramic nanoparticles.[22] New nanomaterials based on metal and oxides of silicon and germanium have demonstrated superplastic behavior, undergoing 100–1000% elongation before failure.[22,23]

Further research in nanotechnology promises breakthroughs in materials and manufacturing, nanoelectronics, medicine and healthcare, energy, biotechnology, information technology and national security.[3,5,7,21,22] Substantial progress also is expected in construction and construction-materials fields.[4,24,25]

Nanotechnology and Change

Nanotechnology has changed and will continue to change our vision, expectations and abilities to control the materials world. These developments will definitely affect construction and construction materials. Recent major achievements include the ability to observe structure at its

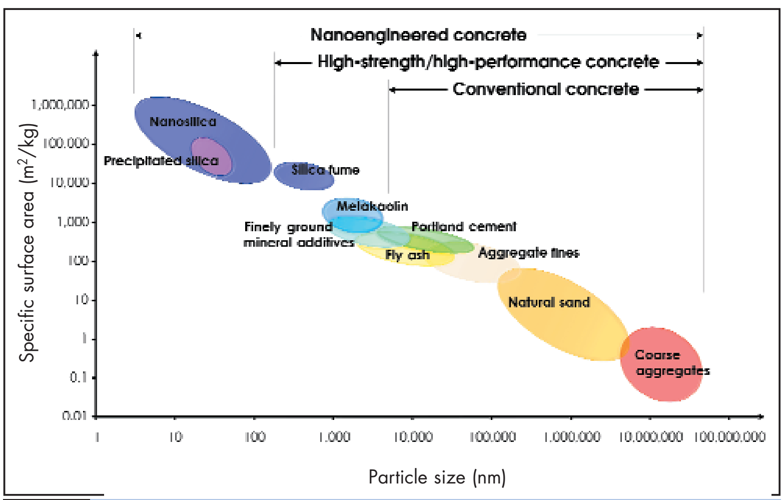

Figure 5 *Particle-size and specific-surface-area scale related to concrete materials.*

atomic level and measure the strength and hardness of microscopic and nanoscopic phases of composite materials.

More-specific achievements are discovery of a highly ordered crystal nanostructure of amorphous C-S-H gel; development of paints and finishing materials with self-cleaning properties, discoloration resistance, graffiti protection, and high scratch and wear resistance; self-cleaning tile, window glass, paints and mortars based on photocatalyst technology; and nanometer-thin coatings that protect carbon-steel against corrosion and enhance thermal insulation of window glass.

Among new nanoengineered polymers are highly efficient superplasticizers for concrete and high-strength fibers with exceptional energy-absorbing capacity. Nanoparticles, such as silica, are effective additives to polymers and concrete, a development realized in high-performance and self-compacting concrete with improved workability and strength. Portland cement, one of the largest commodities consumed worldwide, is obviously the product with great—but at the same time—not completely explored potential.

Better understanding and precise engineering of an extremely complex structure of cement-based materials at the nanolevel will apparently result in a new generation of concrete that is stronger and more durable, with desired stress–strain behavior and possibly possessing a range of newly introduced properties, such as electrical conductivity as well as temperature-, moisture- and stress-sensing abilities.

At the same time, this new concrete should be sustainable as well as cost-and-energy effective—in essence, exhibiting the qualities modern society demands. Nanobinders or nanoengineered cement-based materials with a nanosized cementitious component or other nanosized particles may be the next ground-breaking development.

Nanotechnology remains in its pre-exploration stage; it is just emerging from fundamental research to the industrial application. Therefore, full-scale applications, especially in construction, are limited. However, the tremendous potential of nanotechnology to improve the performance of conventional materials and processes is most promising.

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