Nanotechnology-assisted concrete: Oncoming material in cement industry

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Abstract

Nanotechnology as a new field of material research has many applications in industry. Various nanomaterials e.g. carbon nanotubes, silica, metal oxides etc. can be used for reinforcement of different matrices. This paper reports the state of the art of nanotechnology in concrete. Recent progress in nano-engineering and nanomodification of cement-based materials is presented. An insight for new researches and applications in this area is provided as well.

Keywords – Cement, Concrete, Crack, Nanomaterial.

1. Introduction

Nanotechnology is the next industrial revolution. After a known lecture by Nobel prize owner, Richard Feynman, Nanotechnology was introduced dealing with the production and application of physical, chemical and biological systems at scales ranging from a few nanometers to submicron dimensions. For instance nanotubes, nanopowders etc. have a high surface area with excellent performances for reinforcing, self-healing and other applications. Further research in nanotechnology promises breakthroughs in materials and manufacturing, nanoelectronics, medicine and healthcare, energy, biotechnology, information technology and national security [1]. Substantial progress also is expected in construction and construction materials fields. Better understanding and precise engineering of an extremely complex structure of cement-based materials at the nano-level 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 [2].
The purpose of this article is to report the recent advances in concrete using nanotechnology.

2. NANOMATERIALS IN CONSTRUCTION

The majority of recent nanotechnology research in construction has focused on the structure of cement-based materials and their fracture mechanisms. Fig 1 shows the particle size and surface are of materials related to concrete.
Understanding of nanoscale structure helps to influence important processes related to production and use of construction materials, including strength development, self-cleaning, self-heling, fracture, corrosion and tailoring of desired properties. Nanochemistry with its bottom-up possibilities offers new products that can be effectively applied in concrete technology. One example is related to the development of new superplasticizers for concrete, such as polycarboxylicether (PCE) polymer-based Sky [1]. A nanodesign approach helped to realize the extended slump retention of concrete mixtures. It has been proposed that nanoparticles can be incorporated into conventional building materials and advanced or smart structures e.g. high-rise, long-span or intelligent civil and infrastructure systems.

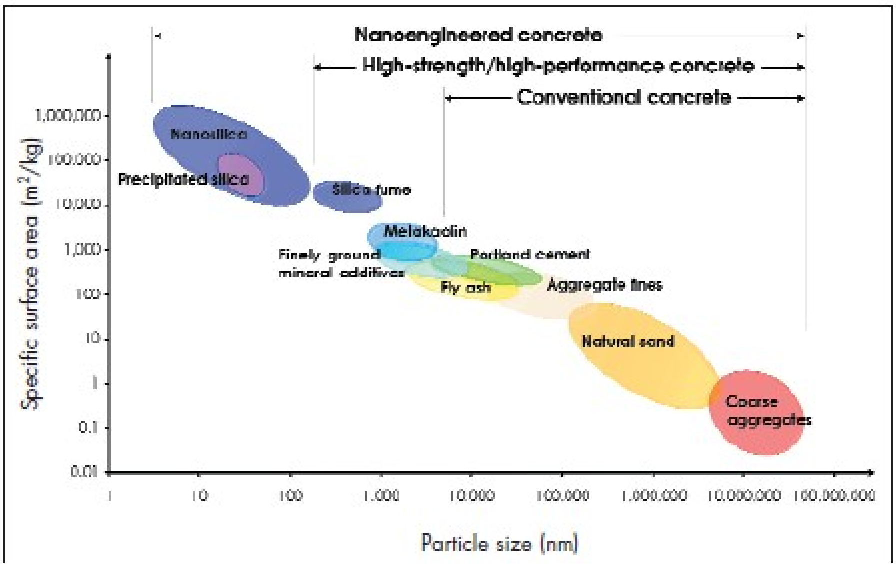

Fig 1. Particle-size and specific-surface-area scale related to concrete materials [2].

Camiletti et al. [3] reported that nano-$CaCO_3$ accelerated the cement hydration process through nucleation, and also acted as an effective filling material in concrete. Saafi [4] applied CNT networks for damage detection in concrete.

As this work is more focused on concrete, a brief introduction to this important material in construction provided bellow.

3. CONCRETE, CHALLENGES AND DEVELOPMENTS

- *Admixtures*

One of the first commercial nanoadmixtures for concrete, Gaia, was developed by Ulmen S.A. and Cognoscible Technologies to substitute for silica fume at ready-mixed concrete facilities certified by ISO 14001,“Environmental Management Systems.” This product is available in liquid form that facilitates the satisfactory distribution of nanosilica particles in concrete. Gaia combines the effects of water reduction and slump increase. According to some reports the concrete mixtures with Gaia exhibit perfect workability without segregation or bleeding. This makes the design of self-compacting concrete an extremely easy task.

The application of Gaia at a dosage of 1.3% (by weight, as a dry content) provides almost a two-fold increase in concrete compressive strength at ages of 7 and 28 d. The early strength of the concrete with Gaia is 68.2 MPa, which is ~3 times higher than that of reference concrete.

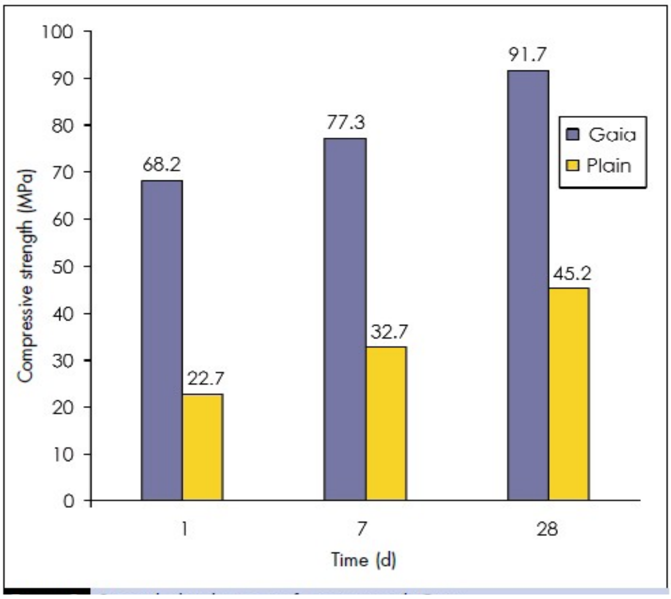

Fig 2. Strength development of concrete with Gaia

- *Mechanical performance*

Using nanomaterials is an established method for mechanical enhancement and functionalization of the polymer. The combination of carbon nanotubes and conventional polymer based fibers and films is another challenge [5]. These wonderful materials can give different properties to the concrete for a variety of applications. For example, silica nanoparticles (nanosilica (Fig. 3)) can be used as an additive for high-performance and self-compacting concrete that has improved workability and strength. [6].

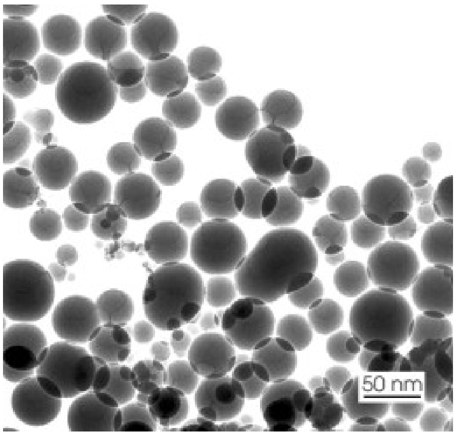

Fig 3. Silica nanoparticles for concrete reinforcement [6]

Li et. al. studying the mechanical properties of cement mortars with nano-iron-oxide and nanosilica demonstrated an increase in compressive and flexural strengths of mortars that contained nanoparticles. It was found that increased nanosilica content improved the strength of the mortars [2]. In other work by Li et. al. a high-volume fly-ash high-strength concrete that incorporated nanosilica was prepared with a water/cement ratio (W/C) of 0.58. Investigation of the hydration process confirmed that the pozzolanic activity of fly-ash can be significantly improved by nanosilica [6].

Based on the available data, the positive action of the nanoparticles on the microstructure and properties of cement-based materials can be explained by the following gfactors:

• Well-dispersed nanoparticles increase the viscosity of the liquid phase, which helps to suspend the cement grains and aggregates, which, in turn, improves the segregation resistance and workability of the system.

• Nanoparticles fill the voids between cement grains, which results in the immobilization of free water (filler effect).

• Well-dispersed nanoparticles act as centers of crystallization of cement hydrates, which accelerates the hydration.

• Nanoparticles favor the formation of small-sized crystals (such as calcium hydroxide and AFm) and small sized uniform clusters of C-S-H.

• Nanosilica participates in the pozzolanic reactions, which results in the consumption of calcium hydroxide and formation of an additional C-S-H.

• Nanoparticles improve the structure of the aggregate contact zone, which results in a better bond between aggregates and cement paste [2].

• Crack arrest and interlocking effects between the slip planes provided by nanoparticles improve the toughness, shear, tensile strength and flexural strength of cement-based materials [1].

4. Conclusions and insights to the future researches

The present paper reports the current state of the field of nanotechnology in concrete industry. The potential of nanotechnology to improve the properties of concrete and result in development of novel, sustainable, advanced cement-based composites with unique mechanical, thermal, and electrical properties is promising and many new opportunities are expected to come in future. The advances in science are enabling engineers to obtain unprecedented information about concrete, from the atomic through the continuum scale, and the role of nanoscale structures on performance and durability. This information is crucial for predicting the service life of concrete and for providing new insights on how it can be improved. however, current challenges need to be solved before the full potential of nanotechnology can be realized in concrete applications, including proper dispersion; compatibility of the nanomaterials in cement; processing, manufacturing, safety, and handling issues; scale-up; and cost. Additionally, introduction of these novel materials into the public sphere through civil infrastructure will necessitate an evaluation and understanding of their performance.

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