An Overview of Nanotechnology in Building Materials

Shane Wong

Sir Winston Churchill Collegiate and Vocational Institute, Thunder Bay, Ontario

Nanotechnology can increase the functionality and durability of building materials like cement, insulation, windows, and weatherproofing. The introduction of nanomaterials to the construction industry can give buildings and infrastructure some degree of: self-repairing, self-cleaning, bacterial- and weather-resistant qualities, increased electrical conductivity, and the ability to break down pollution. Though nanotechnology is still in the early stages of development and can be expensive, increased research may find even more uses for nanotech and lower the cost of its implementation.

Nanotechnology in Concrete

Concrete consists of nano- to macro-sized particles suspended in a calcium-silicate-hydrate (C-S-H) matrix. Most nano-technological alterations to concrete involve some form of interaction with the C-S-H matrix. Some of the materials used in the nanoe-engineering of concrete are nano-silica, nano TiO2, Fe2O3, and carbon nanotubes/nanofibres.

Tests have shown that nano-silica SiO2 can increase concrete’s workability (its ability to fill the desired mold/form), resistance to water, resistance to calcium leaching, and strength. Adding 10% nano-silica increased the compressive strength of cement mortar (the basic ingredient in concrete) by up to 26%. Whereas adding 15% of the larger silica fume only strengthened it by 10%. This is the same as 0.25% nano-silica, which also increased flexural strength by 25%. These increased compressive strengths have the potential to be useful in the foundations of large buildings.

Another promising nanomaterial is nano TiO2 (Titanium (IV) Oxide) which has been shown to give concrete self-cleaning properties.
In addition to self-cleaning; nano-TiO2 gives concrete the ability to photo catalytically break down pollutants like carbon monoxide and volatile organic compounds (VOCs). That makes this type of concrete useful for things like facades and sidewalks in dense urban areas. However this effect becomes less efficient with aging due to carbonation. In addition to the novel effects of TiO2 it also gives concrete increased flexural strength, compressive strength, and abrasion resistance, which could also make it a viable structural material.[1]

There has been limited study on using nano Fe2O3 (Iron (III) Oxide) in concrete mixtures. Like nano-silica and nano TiO2, nano Fe2O3 increases the flexural and compressive strengths of concrete. But it also provides a novel self-sensing property to the concrete. The Fe2O3 causes concrete’s electrical resistance to change depending on the load being applied to it[1]. This property could be used as a replacement for, or in conjunction with, instruments like inclination sensors and GPS units to develop dynamic structure monitoring systems similar to that in use at the Rixos Hotel[2].

Figure 1. UV light neutralizing toxins in TiO₂ enriched concrete
With regards to nano-reinforcement, Carbon nanotubes/nanofibres (CNTs/CNFs) have been studied and show varying degrees of success. The effects changed if multi-walled CNTs (MWCNTs), single-walled CNTs (SWCNTs), or CNFs were used, as well as what method of dispersion was used (Fig. 3) [1].

Other tests using CNTs have exhibited crack-bridging properties in addition to some of the properties in the tests previous (Fig. 2). Crack-bridging could prove useful in concrete that is exposed to the elements by slowing down weathering caused by the freeze-thaw cycle.

Nanotechnology holds tremendous promise in the construction industry. However, many challenges need to be overcome before widespread implementation can occur. The problem of dispersion, particularly in carbon nano-reinforcements, due to their inherent self-attraction and hydrophobicity. The problem of cost as nanomaterials and the tools required to use them are often quite expensive. Safety concerns with this new and relatively untested field. And finally, the alteration of decades old practices in regards to how concrete is used are just some complications preventing mass implementation[1]. The obvious solution for the problems of dispersion, cost, and safety is increased research of nanotechnology.

However, the problem of changing industry practices is unique in that it relies on companies and manufacturers embracing the concept of using nanotechnology in concrete. Despite current conditions, the future holds many possibilities for the use of nanotechnology concrete.

<table>
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<th>Approach Used</th>
<th>Results</th>
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<tr>
<td>CNTs dispersed with and without gum Arabic.</td>
<td>An increase in the Young’s modulus (rigidity) of the concrete with gum Arabic used and a general worsening of mechanical properties without it.</td>
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<tr>
<td>CNTs suspended in water using surfactant admixtures before the mixing of the cement.</td>
<td>CNTs were well dispersed but no significant changes in mechanical properties were observed.</td>
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<tr>
<td>Functionalized MWCNTs lightly coated in polyacrylic acid polymers</td>
<td>Good dispersion as well as a 50% increase in compressive strength and improved workability.</td>
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<tr>
<td>CNFs treated with nitric acid and dispersed with acetone</td>
<td>Good overall dispersion although concentrated pockets of CNFs occurred. Demonstrated increased load bearing capacity.</td>
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<tr>
<td>CNTs and CNFs grown directly on cement particles</td>
<td>A nano-reinforcement content of 20% as opposed to the relatively small percentages used in other tests (&lt;1%). A tenfold increase in electrical conductivity.</td>
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Figure 3. A summary of different experiments with the dispersion of CNTs and CNFs in concrete.
Nanocelluloses

Nanocelluloses are an exceptionally broad category of nanomaterials because it encompass any material nano-engineered from cellulose. They can vary from the shorter nanocrystalline cellulose (NCC) fibres to the longer microfibrilated cellulose (MFC) fibres. These materials can differ greatly in their properties, however, "the scientific interest is based mainly on a few outstanding, basic properties that these materials have in common, i.e., large-scale availability as a renewable material, extraordinary mechanical strength, high specific surface areas and aspect ratios, barrier properties, dimensional stability, biodegradability and biocompatibility."[3]

Depending on the desired purpose, nanocelluloses will lend one or more of these properties to the material being produced.

Nanocrystalline cellulose has a diameter of about 5nm and a length of tens of nanometres[3]. Due to this relatively low aspect ratio and its small fibre size, NCC has many properties in common with nanoparticles and as such it is used in many of the same applications (Fig. 3). It can be used as a filler, or strength enhancer for bulk scale materials like concrete and cements, as well as an individual component in nano-engineered composite materials[3].

Microfibrilated cellulose has a diameter of about 500nm and a length of hundreds of microns. This high aspect ratio gives MFC properties similar to macrofibres, and allow it to be used in fibre based structures and composites[3]. MFC has also been used to create films with an innately low permeability to air and bacteria[4]. If treated to be hydrophobic these films could serve as an effective vapour barrier in buildings. MFC has also been used to make flexible displays for electronics[3]. This same approach could be used to make stronger more flexible windows, which would create new possibilities in architecture with smoother curves on tall buildings to cut down wind resistance and provide more aesthetic appeal.

It is also possible to make MFC aerogels (gels whose liquid component has been replaced by a gas). Aerogels have astounding strength to weight ratios as well as being very good insulators (due to their minimizing conduction through air pockets) [4]. These two properties make them ideal materials for insulation in buildings and combined with the relatively cheap production cost of nanocellulose, could make them feasible for industry-wide mass implementation.

Nanocelluloses have much potential in the construction industry and can be mass-produced from organic waste from agriculture and expired produce[5]. The problem facing their implementation is not enough research has been done by industries to produce practical application methods. Also, there simply has not been enough time since the newer discoveries in the field for changes in industry to occur. The solution to both problems is time, more research done to support nanocelluloses, more practical applications for it to become feasible, and more attention to be the field of nanotechnology as a whole.

Conclusions

The future holds many possibilities for nanotechnology’s use in construction materials. From making stronger concretes, to improving insulation, and many other uses as research in the field goes on. These technological advances also come with challenges that must be overcome before their widespread use. Challenges like cost, production on a mass scale, technological inconsistencies, and the industry’s willingness to accept new approaches. These challenges can be overcome. Given more time and research, nanomaterials could be the standard of building materials.

References