International Journal of Civil Engineering (IJCE)
ISSN 2278-9987
Vol. 2, Issue 2, May 2013, 39-44

APPLICATION OF NANOTECHNOLOGY IN CONCRETE

P. BRIGHTSON[1], M. PREM ANAND[2], D. ANAND RAJELIN[3] & P. JEPARAJ[4]

[1]Assistant Professor, ACEW, Nagercoil, Kanyakumari, Tamil Nadu, India

[2]Assistant Professor, Cape Institute of Technology, Nagercoil, Kanyakumari, Tamil Nadu, India

[3]Assistant Professor, Mar Ephraem College of Engineering and Technology, Kanyakumari, Tamil Nadu, India

[4]Assistant Professor, Bethlehem College of Engineering, Kanyakumari, Tamil Nadu, India

ABSTRACT

Concrete is subjected to new technology; properties like durability, strength, ductility, cleanliness, and water repellency all improve greatly. In particular, nanotechnology should be explored within Civil Engineering to lessen maintenance costs of concrete structures and increase material reliability. This paper will examine the chemical and physical makeup of nano-treated concrete and how certain nano-particles are incorporated into mixtures. The paper will examine the specific benefits of four main types of nano-particles: carbon nanotubes, titanium dioxide, nano-silica, and fly ash. The paper will also address the ethical considerations of concrete and how the application of nanotechnology can solve these problems. Implementing nano-concrete in construction will potentially have a multi-billion dollar impact on the economy which will be explained in further detail in the paper.

KEYWORDS: Civil Engineering, Concrete, Construction, Nano-Silica, Nanotechnology, Nanotubes, Titanium Dioxide

INTRODUCTION

Imagine a material made by an extremely energy-efficient process using abundant materials available all over the world. When this material is mixed with water, which is also plentiful, a construction material is created. This material can mold into any geometric shape, is workable for many hours, and quickly hardens and develops high strength. This seemingly miraculous material is none other than average everyday concrete. Concrete is currently the most commonly used building material on the planet, and the future is not looking any different. Concrete has been invaluable to the construction industry for over two hundred and fifty years, however, as a material it has changed very little in the past century. In today's society, increasingly higher performance demands are placed on structures. These demands expose modern concrete's limitations and call for a more reliable and innovative material. Not only does modern concrete have issues regarding performance, but also environmental impact. Although concrete is not particularly devastating to the environment, the sheer volumes of the material produced worldwide induces a need to monitor its carbon footprint. Also, due to concrete's enormous production, it possesses major implications with the economy. If concrete can be manipulated and made to last longer, millions of dollars could be saved from building more efficient structures. At first glance all of these issues with concrete might seem to be unsolvable problems that limit concrete's utility. An engineer, however, would view these complications as challenges waiting to be conquered. There are numerous ways for engineers to go about solving these issues, but the most promising road to take is exploiting nanotechnology.

NANOTECHNOLOGY

Nanotechnology is the construction and use of functional structures designed with at least one characteristic dimension measured in nanometers. Just how small is a nanometer? To put it in a reasonable perspective, the typical width of a human hair is 50 micrometers. One micrometer is the same length as 1000 nanometers. In conclusion, one nanometer is 50,000 times smaller than the width of a human hair. A common misconstrued belief is that nanotechnology is science fiction and not a realistic application in the present time. This idea, however, could not be more false. In the last 15 years, over twelve Nobel prizes have been awarded in nanotechnology. Working with technology at such a miniscule scale allows scientists to significantly improve physical, chemical, and biological properties. Activity at the nano-scale may not be as predictable as those of a larger one. Nanotechnology can provide an unparalleled understanding about the inner workings of objects, and can positively impact many fields. For example, switching devices and functional units at the nano-scale can exponentially increase computer storage. New biological sensors can detect cancer at a much early stage. Nanotechnology is especially relevant in the field of civil engineering. With the power of nanotechnology, steel cables and joints can be strengthened. Coatings and paints can be given insulating properties. The main way this science is being utilized in civil engineering is through the improvement of materials such as glass, steel, and lastly, concrete. There are various ways to incorporate nanotechnology into concrete that will greatly improve its desirable properties, such as durability, strength, ductility, and cleanliness. The four innovations to be discussed in this paper are carbon nanotubes, nano-silica, titanium dioxide, and fly ash.

CARBON NANOTUBES

One of the most revolutionary concepts in nanotechnology is the use of carbon nanotubes in various types of materials. Carbon nanotubes are cylindrical structures of carbon measured to be nearly a nanometer in diameter, see figure below. The thickness of a single nanotube is only a billionth of a meter, making it comparable to the size of a DNA Helix, a common virus, or 10 hydrogen atoms lined up side-by-side. These carbon nanotubes were first discovered in 1952, but were largely ignored until 1990 upon rediscovery in Japan. In modern day science, these nanotubes are sought after for their remarkable mechanical properties, and researched heavily to evaluate where they can be used most effectively. The strength of these carbon nanotubes is eight times greater than that of steel while remaining one-sixth the density of steel. Single-walled nanotubes can also be overlapped by other single-walled nanotubes to create a system of multi-walled nanotubes that can slide telescopically over each other with no resistance. These nanotubes can be electrically conducted within a system, and can also conduct heat very well along the axis of the tube. The main prohibitive factor for these carbon nanotubes is the cost. As technology worldwide improves with time, more nanotubes are sure to be made and eventually the price will drop enough for carbon nanotubes to be used more regularly.

These carbon nanotubes cannot be found in nature, which explains the high price for purchasing these materials. There several different processes for making carbon nanotubes and all of these methods require extensive amounts of expensive machinery and very well trained technicians and scientists working with those machines. Production is still in its infancy for nanotubes, but overtime the cost of the technology required to build these materials will lower and make the carbon nanotubes themselves more affordable.

Extensive amounts of research have been done to find a way to optimize the use of carbon nanotubes particularly in concrete. Implementing just a small amount of these nanoparticles at a percent of .022 of the weight of the total cement shows a significant difference in strength, ductility, and stiffness. The problem with working with such small, thin, and strong particles is the tangling or aggregation of the tubes. Dispersion is the number one issue when dealing with these carbon nanotubes, other than cost of the nanotubes, which engineers cannot control. The problem with dispersion is the high van der Waals and electrostatic forces. These forces on a general scale are very weak, because they are only the product of the charge difference between molecules. The positive and negative ends of each molecule attract one another while two equal charges repulse one another. This causes a huge problem when working in nanotechnology that operates on particles which are essentially the size of molecules.

In one case study done by Kay Wille and Kenneth Loh, they experimented with dispersion techniques of implementing multi-walled carbon nanotubes into concrete during the mixing process. The most successful dispersion technique used in the experiment was by placing the nanotubes in a polyelectrolyte solution. This solution would suspend the nanotubes as they were poured into the cement mixture and prevent much of the clumping together of nanoparticles that occurred when other methods were used. This solution did not affect the workability, or viscosity, of the cement compared to the reference mixture, which shows that the dispersion had not adverse effect. The strength of the concrete increased slightly from 200MPa to 212MPa and the bendability of the material didn’t change much]. These insignificant changes could account for the relatively low amounts of carbon nanotubes being only .022% of the mixture. Although, when tests were conducted to examine the relationship between the nanotubes and the steel fibers within the concrete mixture; the results showed that even this very small amount of nanoparticles drastically improved the bonds between steel fibers in all tests. This series of experiments proved that dispersion of the carbon nanotubes can be efficient and even the smallest amount of nanotubes can improve the steel fiber bonds within the mixture. It isn’t a problem that the strength and ductility hadn’t increased by a large amount, because it has already been proven that carbon nanotubes improve these mechanical properties, but only with more quantity of nanoparticles. The next step is to reassure that the dispersion technique used can work with a higher concentration of nanotubes. Studies like the one carried out by Kay Wille and Kenneth Loh prove that the use of carbon nanotubes is becoming more practical. We are becoming more knowledgeable of the properties associated with nanotubes and with just a few more breakthroughs the use of carbon nanotubes will become common and efficient. Once the construction industry begins to recognize carbon nanotubes as an excellent resource to improve the mechanical properties of structures, infrastructure will improve greatly and less maintenance will be needed to fix structures that would otherwise breakdown faster.

TITANIUM DIOXIDE

Another important nanoparticle being used in the construction industry is Titanium Dioxide. This compound is added to concrete to improve various chemical and physical properties of the concrete. This substance has a wide variety of benefits ranging from the concrete having a whiter and longer lasting color, and the new concrete being able to break down air borne pollutants. Although it still hasn’t made the complete transition from experimental project to commercial product, this is still one of the most commonly used nanoparticles in the modern day construction and has been used in concrete structures in Japan, and some parts of Europe.

Titanium Dioxide can attribute its special properties to its catalytic nature. The TiO_2 works as a catalyst in the reaction that takes UV light and converts that energy to decompose organic materials like dirt, biological organisms, air borne pollutants, nitrous oxide, and sulfuric oxide. The products of this reaction are water, oxygen, nitrate, sulfate, carbon dioxide, and some other molecules; all are relatively benign to the environment. In particular the most important pollutant is the nitrous oxide, because it is produced by traffic and accounts for the formation of smog and ozone. The natural process of decomposition is speeded up by the Titanium Dioxide and the nitrous oxide is converted to nitrate in a two-step chemical process, shown in the equation below. Additionally, the hydrophilic nature of the TiO_2 allows the nitrate and other products to be cleaned away from the concrete very easily. Hydrophilic means that the Titanium Oxide allows water to stick closely to the surface, so as the water runs across the surface it will remove the excess particles. Therefore, simply washing off the concrete with distilled water or waiting for a rainstorm will remove the contaminants from the surface.

NO + OH (in the presence of $TiO_{2)}$ ——→ $NO_2 + H^+$

NO_2+OH (in the presence of $TiO_{2)}$ ——→ $NO_3^- + H^+$

(Equation of Decomposition of Nitrous Oxide)

Utilizing these properties to their full potential has become a goal for many scientists. To optimize the benefits of Titanium Dioxide it needs to be highly concentrated at the surface without risking the substance to weathering or abrasion. There are two methods to applying this photo-catalytic material to the concrete. One way is to mix the TiO_2 directly into the concrete giving the pigment a more appealing white color, but the Titanium Dioxide isn't always highly concentrated at the surface. The other application is to implement the nanoparticles into the weathering layer which focuses the TiO_2 at the surface. Both methods are effective, but it depends on the structure being made and which benefits are being sought after. Also, the photo-catalytic properties are optimized when the light intensity is high, temperature is high, and relative humidity is low. This is perfect for applying this material to urban areas, because these conditions are reached in the summer when the smog concentration is at its peak and Titanium Dioxide would be extremely efficient for reducing air pollution when it is most needed.

Such projects like that of Richard Meier & Partners Architects LLP, an architectural firm, are working to try and implement this photo-catalytic material into concrete. They completed the Jubilee Church in Rome in 2003, as shown below. This structure contained "256 precast, post-tensioned concrete elements assembled into curved white "sails" that rise 85 feet into the sky". Over 12,000 man-hours went into developing and testing the new cement samples that contained TiO_2. The group claims that the concrete in the church will keep the church clean for an estimated 1000 years, which was the overall project goal. Small projects like this have been accomplished in some parts of Europe and in Japan, but the idea is still beginning to be introduced here in North America.

The environmental effect of using this particular type of nanotechnology could be great. The self-cleaning aspects of the concrete will eliminate the need to use solvents to clean buildings, indirectly taking away another pollutant. The Titanium Dioxide can also lower heat buildup within dense urban areas, because the lighter color of the concrete will absorb less heat. A study has shown that using photo-catalytic paving absorbed 15% of nitrous oxide emitted from cars, which is more than if both sides of the street had trees planted. Another study has shown that smog and other pollution will be reduced by nearly 80% if all structures in an urban area contained this nanoparticle.

NANO SILICA

The third particle that has the ability to drastically improve the properties of concrete is nano sized silicon dioxide, known as nano-silica. When utilized correctly, this nanoparticle can block water penetration, help to make the concrete more dense, and also reduce the impact concrete has on the environment. To explain the usefulness of nano-silica, we need to go back to the basics of what composes concrete. A common misconception is that concrete and cement are two interchangeable words for the same exact material. However, this is not the case. Cement is a construction material made from limestone, calcium, silicon, and a few other ingredients. Concrete on the other hand is a material that uses cement to bind together crushed stone, rock, and sand. In fact, it is the cement content in concrete that causes the harmful carbon dioxide emissions. It is an engineer's duty to protect the environment, so this problem must be given some attention. One of the ways to reduce amount of cement in concrete is the use of nano-silica. This nanoparticle can be produced in multiple ways, such as through the vaporization of silica and a precipitation method. In a process known as the sol-gel process, Na_2SiO_4 is added in a solvent. The pH of the solution is changed until the precipitation of silica gel is reached. Lastly, the gel is dried and burned to produce a concentrated substance suitable for use in concrete. Once the nano-silica is added to the concrete mixture, it reacts with calcium hydroxide (CH) to form calcium silica hydrate (CSH), which is the strength carrying structure of the concrete. The nano-silica can also fill the voids in the concrete mixtures, which will in turn increase the final density of the material. Dr. Laila Raki is a Canadian scientist who has recently done research on the effect of nanotechnology in the density of concrete. According to Dr. Raki, filling in the holes of concrete is important because “cement pores are a route for salt and other chemicals to enter concrete and break it down.” Not only can nano-silica strengthen the concrete and make it more dense, but also positively affect its water permeability. In a recent test, nano-silica particles ranging from 10 to 20 nanometers were added to concrete mixes and evaluated. The results show that these particles can block water from penetration the surface by reacting with $Ca(OH)_2$ crystals and reducing their size, making the surface of the material much denser.

One of the things that discourages people from implementing nanotechnology in concrete is its steep cost. Fortunately, a new nano-silica has been created that can be produced in high amounts for low expenses. Cement is not only the most environmentally harmful ingredient in concrete, but also the most costly. Nano-silica has the potential to replace cement in the mixture, which would drive down the cost of concrete and as well as reduce its carbon footprint. In conclusion, the addition of nano-silica can produce a concrete with improved performance, lower costs, and also a lessened adverse effect on the environment.

FLY ASH

Another option in the world of nanotechnology and concrete is the addition of fly ash to the mixture. Fly ash is known as a supplementary cementitious material, or SCM. Although the use of fly ash in concrete is not a groundbreaking phenomenon, it is crucial to the advancement of modern concrete. Fly ash primarily comes from burning coal found in mountain chains across the country, such as the Appalachian Mountains. It consists of the mineral constituents of coal that do not burn, such as mercury, lead, and arsenic. As was discussed before, cement reacts with water and forms a gel that binds together aggregates, such as rocks and sand, to form concrete. During the “curing” process, when the concrete gel begins to harden, some hydrated lime is left behind. The addition of fly ash allows the lime to cure as well, simultaneously making the concrete stronger and filling in the gaps. Fly ash is made up of tiny spherically shaped particles that act like ball bearings, which is why it can easily fill in holes.

It was explained earlier that the cement content in concrete is that main culprit for its negative environmental impact. Nano-silica was the particle that could be utilized as a replacement for cement, effectively reducing the amount of harmful carbon dioxide emissions from concrete. Fly ash is the second particle that is being used for this exact purpose. Concrete mixtures with fly ash as opposed to nano-silica are less expensive and more commonly used today. Many mixes in which 25% of the cement content is replaced with fly ash are currently in use, while some designers are specifying that their concrete replaces at least 50% of the cement with fly ash. However, fly ash puts forth a few drawbacks that are necessary to discuss. First, concrete mixes with high volumes of fly ash must be thoroughly tested before each application because the chemistry of fly ash is less predictable than that of normal cement. Also, fly ash mixtures cure and gain strength at a slower rate, so these projects must be managed differently in order to accommodate for this variable. Lastly, due to the fact that fly ash includes a variety of heavy metals, questions remain about whether these potentially hazardous ingredients might complicate the disposal or reuse of the concrete years down the road.

CONCLUSIONS

The construction industry has been around for centuries and is in no way a new idea. It has, however, progressed into the advanced science we know it to be today. The same can be said for nanotechnology. It is not a new breakthrough technology that is unrealistic for the present time. Nanotechnology has also developed as the result of technological and scientific advances, and it is the logical progression of science due to the increasing need to understand the nature of our world at smaller and smaller scales. Nanotechnology is using extremely small pieces of material in order to create new large scale materials. Working with such small particles allows for manipulation of the chemical and physical aspects of the material, therefore magnifying its positive properties and eliminating its negative ones. This powerful concept can be directly applied to civil engineering, specifically materials used in construction.

As mentioned previously, concrete is used more than any other man-made material on the planet. As of 2009, six billion cubic meters of concrete are produced each year, about 1 for every person on earth. This enormous number tells us that concrete needs to be as efficient, reliable, and environmentally friendly as possible. However, the concrete in use today all around the world does not come close to meeting these standards. The estimation that 10% of concrete fails prematurely is an eye opening statistic and a major problem. Also, modern concrete produces about 6% of the total worldwide man-made carbon dioxide production, which is the leading cause of global warming. The concrete in use today is inconsistent, hazardous to our environment, and displeasing to the eye. These shortcomings are unacceptable for the construction industry's most widely used material, and they call for concrete to be brought into the 21st century. The most effective way to do accomplish this task is through the use of nanotechnology. Not only can nanotechnology outright improve the performance of concrete, but also make it more visually appealing and environmentally friendly.

America's infrastructure is literally crumbling all around us. Over 30% of the highways and roads in the United States are inadequate and in poor shape. In 2008, the I35 Mississippi River Bridge collapsed during rush hour cost 13 lives and injured another 145. This bridge was made out of concrete. It is apparent that it is time for civil engineers to buckle down and start modernizing our infrastructure. Concrete with technological components at the nanoscale such as carbon nanotubes, titanium dioxide, nano-silica, and fly ash, can transform our world and make the infrastructure more efficient, durable, and environmentally friendly.

REFERENCES

1. Z. Wang (2010) "What is Nanotechnology". *Nano Research Group of Georgia Tech*
2. T. Harper (2003, January) "Nanotechnology". *IOPScience.* Volume 14, Number 1
3. S. Mann (2006, October) "Nanotechnology and Construction." *Institute for Nanotechnology (UK).*
4. C. Journet, P. Bernier. (1998, February) "Production of Carbon Nanotubes." *University of Montpellier, France.*
5. K. Wille, K Loh (2010, January) "Nanoengineering Ultra-High-Performance Concrete with Multiwalled Carbon Nanotubes" *Transportation Research Record*. Pages 119-126.
6. M. Chusid. (2012) "Photocatalysts, Self-Cleaning Concrete." *Concrete Décor.*
7. A. Beeldens. (2009) "The Application of TiO_2 as a photo-catalyst…" *Belgian Road Research Centre*.
8. J. Belkowitz, D. Armentrout. (2010) "An Investigation of Nano Silica…" *National Ready Mixed Concrete Association*
9. J. Belkowitz, D. Armentrout. (2010) "An Investigation of Nano Silica…" *National Ready Mixed Concrete Association*
10. (2009, February) "Using Fly Ash in Concrete" *Environmental Building News.* Volume 18, Number 2