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APPLICATION OF NANOMATERIALS IN THE SUSTAINABLE BUILT ENVIRONMENT

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Abstract: Nanotechnology is widely regarded as one of the twenty-first century's key technologies, and its economic importance is sharply on the rise. In the construction industry, nanomaterials has potentials that are already usable today, especially the functional characteristics such as increased tensile strength, self-cleaning capacity, fire resistance, and additives based on nano materials make common materials lighter, more permeable, and more resistant to wear. Nonomaterial are also considered extremely useful for roofs and facades in the built environment. They also expand design possibilities for interior and exterior rooms and spaces. Nano–insulating materials open up new possibilities for ecologically oriented sustainable infrastructure development. It has been demonstrated that nanotechnology has invented products with many unique characteristics which could significantly provide solutions current construction issues and may change the requirement and organization of construction process. This paper examines and documents applicable nanotechnology based products that can improve the sustainable development and overall competitiveness of the construction industry

Keywords: Nano Materials, Concrete, Thermal Insulation, Flame Retardant, Thermal Energy Storage

1. Introduction

Building and construction industry is a prime consumer of world's material and energy resources which accounts nearly for 40%of usage. The industry utilizes natural and synthetic materials which include cement, steel, aggregates, wood, glass, textiles, plastics, foams etc. The current tendency and demand towards more sustainable "green" practices has imposed a tremendous pressure on this material and energy usage in the Building Environment for improvements and conservation (Elvin, 2007). Nanotechnology, the manipulation of matter at the nano scale plays a key role in this matter where it provides answers for current construction related problems. Thus the potential for energy conservation and reduction of resource consumption, waste, toxicity and carbon emissions towards more sustainable "Green Practices" is significant.This paper mainly focuses on better properties concrete, thermal insulation, flame retardant, thermal energy storage, and self cleaning and antimicrobial effect for sustainable built environment.

2. Concrete

Concrete is the most widely used material in the built environment. Concrete mainly consists of cement, aggregates, water and admixtures. Most of the concrete is made up of aggregates which are inert granular materials such as sand, crushed stone or gravel (Tabsh and Abdelfatah, 2009). Cement acts as the main binding phase in concrete. The expansion of the construction industry it is necessary to develop low cost and more efficient types of concrete while maintaining sustainability.

2.1. Incorporating Nano Materials to Concrete- The Present Status

Nano engineering or nano modification to the cement based materials is an active area of research at present(Sanchez and Sobolev, 2010). But, comparing with the other fields, concrete has been slow to catch the emerging enhancements of nano technology. This is mainly due to the lack of basic understanding of concrete at nano level and the lack of broad understanding of what nano modification means to concrete (Garboczi, 2009). The recent developments of the experimental techniques available have facilitated to study the concrete at micro and nano levels. Concrete is a nano-structured multi phased composite material consisting of an amorphous phase, nano meter to micro meter sized crystals and bound water. The reactions within the concrete occur through macro, micro and nano levels (Sanchez and Sobolev, 2010). Therefore, addition of suitable nano particles into concrete can alter many properties of concrete. The effects of adding various nano particles to concrete are described below.

2.1.1. Addition of Nano Silica into Concrete

Nano Silica has been found to increase the strength, flexibility, workability and durability of concrete. The nano Silica particles increase the viscosity of the fluid phase of concrete and fill the voids between cement grains. It reacts with Calcium Hydroxide and results in more Calcium Silicate Hydrate (CSH). Almost all the mechanical and transport properties of concrete are controlled by CSH which is a nano-porus, nano-structured material(Garboczi, 2009). Nano Silica acts as a nucleation site for preparation of CSH which results in high strength than conventional concrete (Sobolev et al., 2009, Hosseini et al., 2009, Vera-Agullo et al., 2009, Sanchez and Sobolev, 2010). Incorporating nano Silica has improved the hydration process of cement (Belkowitz and Armentrout, 2010, Sanchez and Sobolev, 2010). This is mainly due to the large reactive surface area of nano particles.

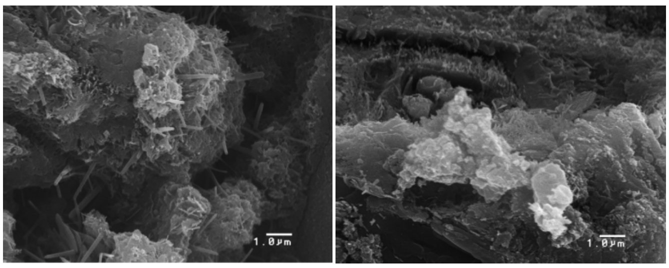

Fig: 1(a) **Fig: 1(b)**

Fig. 1: (a) SEM micrographs of Ordinary Portland Cement Paste and **Fig.1:**(b) Paste containing Nano Silica (Jo et al., 2007)

2.1.2. Addition of Carbon Nano Tubes (CNT) into Concrete

Carbon Nano Tubes (both Single Walled (SWCNTs) and Multi Walled (MWCNTs)) is another material which can be used to enhance the properties of concrete.

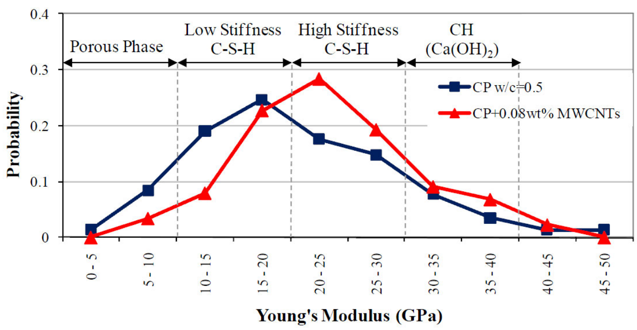

Fig.2: Probability plot of Young's Modulus of 28 days cement paste(w/c=0.5) and cement paste reinforced with 0.08wt% MWCNTs (Metaxa et al.)

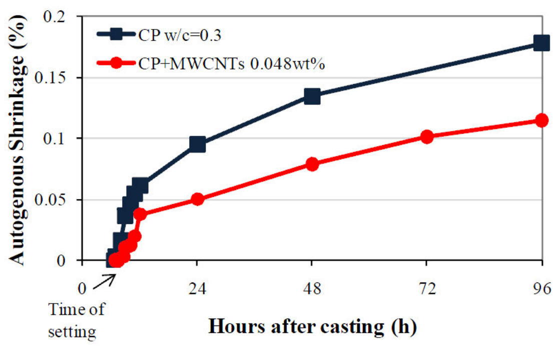

Fig.3: Autogenous shrinkage of cement paste (w/c=0.3) and cement paste reinforced with 0.048wt% MWCNTs (Metaxa et al.)

CNTs display a very high theoretical strength which is 100 times more than that of steel while just having only one sixth of the specific weight of steel(Li et al., 2005). Incorporation of CNTs increases the amount of high stiffness CSH and also reduces the porosity of the CSH phase resulting increase in Young's Modulus, flexural strength, compressive strength and durability and decrease in autogenous shrinkage (Metaxa et al., Li et al., 2005).

2.1.3. Addition of Nano TiO_2 into Concrete

There has been few research carried out to study the effect of nano TiO_2 in concrete mixes. As TiO_2 is an inert material it will not participate in the reaction within the cement paste but the rate as well as the peak of hydration of concrete has shown to be increased as shown in Fig 4 when nano TiO_2 is added due to the heterogeneous nucleation. Nano TiO_2 improves Compressive and Flexural Strengths and enhance the abrasion resistance of concrete (Jayapalan et al., 2009).

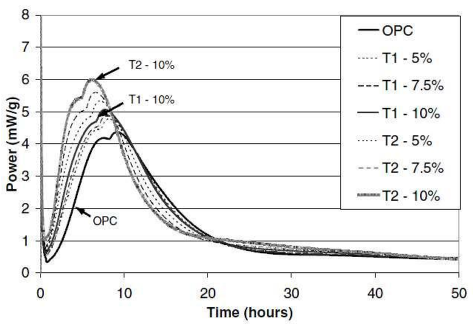

Fig. 4: Rate of Hydration of TiO_2 –blended cements (Jayapalan et al., 2009)

2.1.4. Addition of Nano Fe_2O_3 and Al_2O_3 into Concrete

Partial replacement of cement with nano Fe_2O_3 particles has shown to increase the flexural and compressive strengths of concrete (Nazari et al., 2010a). Another nano material which has been incorporated with concrete is nano Alumina. It has been shown that partial replacement of cement with nanophase Al_2O_3 particles improves the compressive, flexural and split tensile strengths of mortar but decreases its workability and setting time(Nazari et al., 2010b, Nazari et al., 2010c).

2.1.5. Summary of the effects of Nano Materials on Strength of Concrete

A comparison of the percentage increase of flexural and compressive strengths with the addition of nano particles is shown in Figure 5.

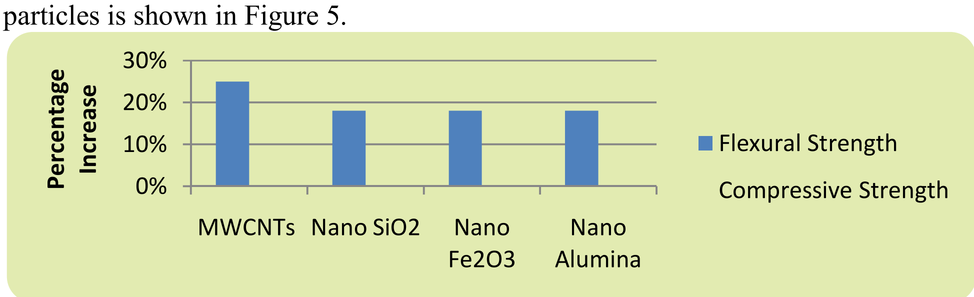

Fig. 5: Percentage increase in Compressive and Flexural Strengths with the addition of nano Particles (Sobolev et al., 2009, Hosseini et al., 2009, Vera-Agullo et al., 2009, Sanchez and Sobolev, 2010), Metaxa et al, Nazari et al., 2010b, Nazari et al., 2010c)

2.1.6. Issues regarding incorporation of Nano Materials into Concrete

It is important to obtain good dispersion of these nano materials to avoid agglomeration and to increase the linkage of nano materials with the binding phase of concrete. Large aggloromates and bundles as seen in Fig 6(a) can be noticed when no dispersing agents are used (Konsta-Gdoutos et al., 2010). Adding an effective superplasticiser, ultrasonification, high speed mixing and chemically functionalizing the surfaces of the nano materials have shown to increase dispersion of nano materials within the matrix phase and enhance the bonding (Kowald and Trettin, 2009, Shah et al., 2009, Sobolev et al., 2009, Cwirzen et al., 2009).

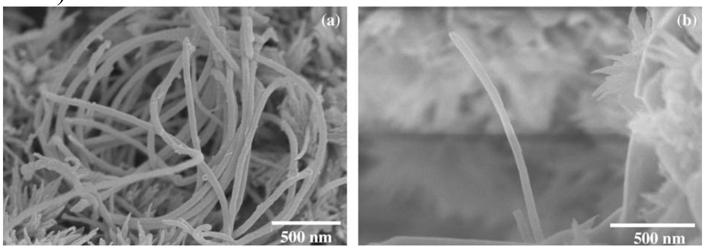

Fig.6: SEM images of cement paste fracture surfaces reinforced with undispersed and dispersed MWCNTs (a) and (b), respectively.(Konsta-Gdoutos et al., 2010)

3. Thermal Insulation

Building insulation will be one of the main focuses, where the demand for more energy efficient buildings is expected to grow significantly in coming years. The presence of glass surfaces and the insulating capacity of the outer cladding are the main reasons for heat loss and gain within the building envelope (Scalisi, 2009). Nanoscale materials provides a far better solution in building insulation due to their high surface-to-volume ratio which enable them to trap still air with in a thin layer of material. The current product range on insulation varies among paints, coatings, thin films or rigid panels.

3.1.Nansulate

Nansulate® coating is a patented insulation technology that incorporates a nanocomposite called Hydro-NM-Oxide, a product of nanotechnology. It’s an excellent insulator due to its low thermal conductivity and the nanomaterial used. Test results for Nansulate® from independent laboratory shows that thermal resistance (1/U) of the wall section coated with Nansulate® was increased by 28.98% (Test Method:UNI EN ISO 8990:1999) (www.nansulate.com).Nansulate can be directly applied to the existing buildings without incurring any post-construction addition, thus creates tremendous energy saving with existing buildings. Nansulate coating thickness on an applied surface is around 200 microns DFT (approximately 3 coat coverage) with very high savings on space reduction (Industrial-nanotech, inc.2010.).

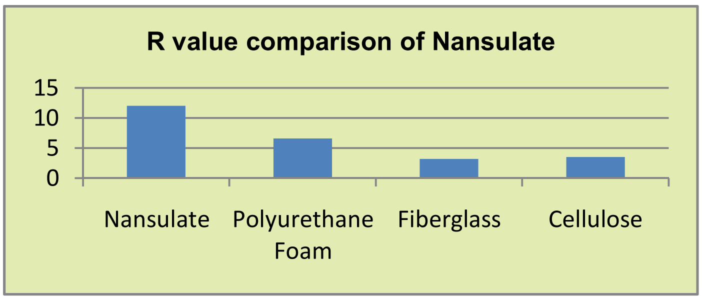

Fig.7: R value (Thermal Resistivity) comparison of Nansulate Shield, especially designed for the construction industry with conventional insulating materials (Elvin, 2007).

3.2. Aerogel

Nanoporous insulation materials like aerogels, an ultra-low density solid provides a superior solution for insulation. The aerogels for thermal insulation used today are most often silica or carbon based with approximately 96% of their volume being air. Silica aerogel is a promising nanocomposite material for applications in buildings because of its high visual transmittance and its low thermal conductivity. Apart from their low thermal conductivity its load bearing capability makes it suitable for evacuated transparent insulation applications

Fig.8: Aerogel, The world's lightest solid (Elvin, 2007).

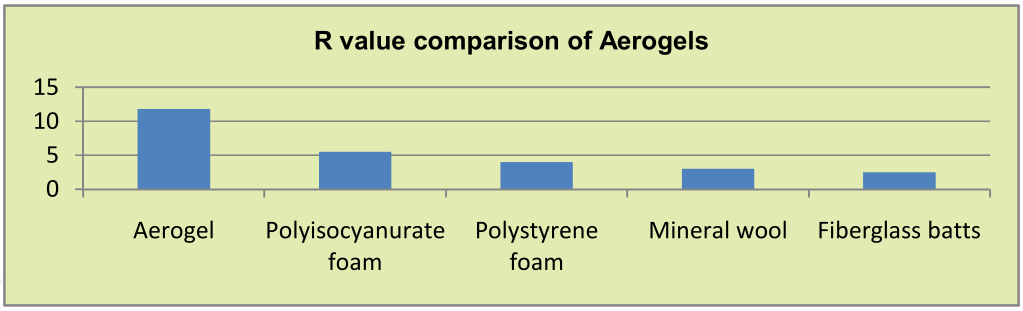

Fig. 9: R value comparison of Aerogels (Elvin, 2007)

4. Flame Retardant

Flame retardant effect can be results as a combination of several kinds of nanocomposites. Due to its low price, many research focused on the production of nanoclay containing composites to achieve these properties but CNT is also heavily used in research for flame retardant materials. The newly developed materials possess properties like reduced flammability, less toxic gases release and less smoke products compared with the traditional flame retardant materials (Zhang, 2005).

4.1.Nanoclay

Research done on polyamide 66/organoclay(nanoclay) (PA66/OMT) nanocomposites shows improved flame retardant properties. The peak HRR (PHRR) is the most important parameter to evaluate fire safety (Zhang, 2005). It shows that pure PA66 burns very fast after ignition and reaches a sharp peak on the HRR curve while the addition of OMT shows a great decline of HRR and the sharp peak tend to be a platform (Song *et al*., 2008).

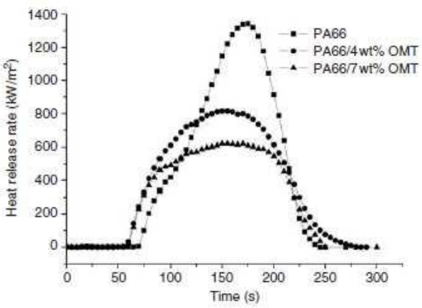

Fig. 10: Comparison of heat Release rates, PA66 and PA66/OMT nanocomposites (Song *et al*., 2008).

4.2.Carbon Nano Tubes

Carbon nanotubes (CNTs) attracted much attention due to their excellent properties as a nanomaterial used for making polymer nanocomposites in recent years (Reim *et al*., 2005). Research done on improving flammability of Ethylene–vinyl acetate (EVA) based composites using Multi wall Carbon Nanotubes shows that the possibility of delaying both the ignition time and reduce the flammability (HRR) of a polymermatrix like EVA by adding a small amount of MWNTs (Peeterbroeck *et al*., 2007).

5. Thermal Energy Storage

5.1.Phase Change Materials

Phase Change Materials (PCMs) are often considered for latent heat thermal energy storage (LHTES) applications. Thermal storage can be part of the building structure due to the advent of PCM implemented in gypsum board, plaster, concrete or other wall covering materials (Castellón *et al.,* 2007*)*. The main drawback that hinders the application of PCMs is their low thermal conductivity (Zeng *et al*., 2009). Paraffin is commonly available PCM material with promising benefits because it has a large latent heat and low cost, and is stable, non-toxic and not corrosive. Research has done to overcome the low thermal conductivity problem of paraffin using exfoliated graphite nanoplatelets (xGnP).

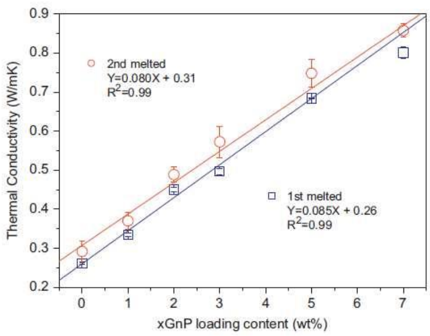

Fig. 11: Thermal conductivity of paraffin/xGnP composite PCMs by melting times (Kim and Drzal, 2008).

6. Self Cleaning and Antimicrobial effect

Need for achieving a cleaner hygienic surface is highly desired in current architectural practices. In a building environment, the primary cleaning actions includes the removal of everyday dirt, dust, or other things that naturally appear on windows or other surfaces in buildings (Ashby *et al*., 2009).

Fig.12: This fabric membrane structure at the Hyatt Regency in Osaka uses a photocatalytic clear coat based on TiO_2, which creates antibacterial effect. (Ashby *et al*., 2009)

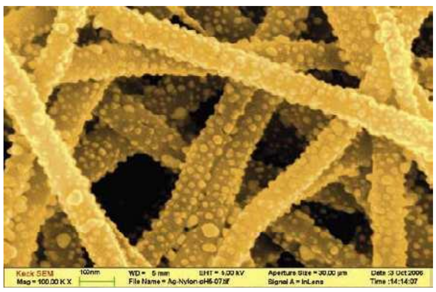

Fig.13: SEM image of nanofibers with silver (Ag) nanoparticles for antibacterial gowns and active surfaces such as carpets and upholstery. (Ashby *et al*., 2009).

Commercials products are available for self-cleaning surfaces with the invention of photocatalytic coatings containing titanium dioxide (TiO2) nanoparticles. These TiO2 particles degrade organic dirt and stains when it is exposed to ultraviolet (UV) light. When the surface is subjected to rain or simple washing hydrophilic action of TiO2 carries out the loosened dirt particles from the surface.

Surfaces which exhibit "antibacterial" properties either kill or inhibit the development of bacteria which causes deleterious effects such as discoloration, staining, or odours (Ashby *et al*., 2009). One such approach is to use copper or silver nanoparticles as a coating on base materials or incorporated directly in the surfaces of the base materials. Apart from the proven history of antibacterial effect of these materials, much larger surface area of nanoparticles helps to provide a sound antibacterial effect.

7. Conclusion

Nanotechnology is a promising field in terms of environmental improvements including energy savings and reduced reliance on non-renewable resources, as well as reduced waste, toxicity and carbon emissions. It's applications in the building industry is expected to show a significant boom in the coming years due to international urge for "more greener" build environment. When considering the built environment, concrete is the main construction material. Better understanding of the properties of concrete at nanoscale can lead to improve the functionality of concrete. The influence of addition of nano particles such as Nano Silica ,nano Al_2O_3, nano TiO_2 and nano Fe_2O_3 in the correct proportions and methods into concrete can increase the mechanical and transport properties, rate of hydration, durability and many other properties. Moreover energy conservation and reducing green house emissions in the building environment can be a reality due to nanomaterials emerging as insulations and energy storage materials. Enhanced insulation material coupled with thermal energy storage properties can reduce the operational energy consumption in a build environment to a great deal. Other applications like self cleaning and antimicrobial surfaces will reduce the resource consumption and lengthen the life cycle of material usage in the industry, thus will drive towards sustainable practices.

As markets are full of uncertainty especially when new technologies are introduced, the application of nanotechnology will also face challenges in terms of material cost, construction industry resistance and public awareness about nanotechnology. But with the outstanding benefits offered by nanotechnology, it will outperform all the obstacles and it's expected that these exciting materials and products that will dramatically change the way future buildings are made and the best is yet to come.

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