Nanotechnology; Advancements and Concerns in Construction Industries

Emmanuel Emem-Obong Agbenyeku, Edison Muzenda, and Innocent Mandla Msibi

Abstract**—**This paper lays emphasis on recent developments pertaining the utilization of nano-materials in active areas of construction industry around the globe. The pertinence of nanotechnology towards the sustainable growth of the construction industry worldwide has become of chief interest. The paper introduced and highlighted a few applications of important nano building components presently in circulation. The paper further documented a few merits of nanotechnology and demerits in terms of severe health risks linked to the use of nanotechnology. Developing countries should therefore be technologically prepared before the incorporation of this growing technology into their systems. Some parts of the developed world have successfully engaged in construction projects using nanotechnology. The dangers however, should be generally known and remedies sought after such that nano building resources could be harnessed and effused safely and beneficially into societies.

Keywords**—***Nanotechnology, Carbon nano tube, Nano silica*

I. Introduction

NANOTECHNOLOGY is a branch of chemical and material science dealing with nano particles. A nano particle refers to a material particle which has at least one of its dimensions in nanometers or in 10^{-9}m. It is also the study of materials at nano scales. Over time, as reported by [1] the properties of the particles have been observed to radically change when they are pulverized into nano sizes. A copper wire is reported to bend because of the movement of its atoms at about 50nm scale. However, copper particles smaller than 50nm are known to be extremely hardened materials that display completely different characteristics i.e., malleability and ductility as compared to those larger than 50nm [2]. In the case of gold nano particles, they possess a much lower melting point (about 300˚C) than the bulk gold (about 1064˚C) [3]. As such, the knowledge that the characteristics of the particles change as they approach nano sizes have been considerably documented by engineers and scientist in fields of chemistry, physics, electronics, medicines etc., yet they still are not generally known. Construction and building components are very vital engineering areas gaining attention from recent past. Materials such as; soil, aggregates, concrete, steel, bricks, plastics, glass, timber, metals etc., have been reported as important materials under constant study for reasons of improvement and to serve as substitutes to the costly conventional products [4]. Stone aggregates and timber are considered the oldest materials used by early humans for shelter against wild beasts and the elements. Like every other species, building materials have passed through an evolutionary era and presently concrete and steel are the modern giants in construction industry. With the advancement in technology, newer and smarter materials have been discovered and developed by engineers and scientists in a large area of interest. The utilization of nanotechnology and nano-materials in diverse areas of engineering has eventually emerged as a new initiative under continuous investigation and propagation. The high strengths and low densities of nano-materials have been very advantageous in solving numerous challenges in construction industries. Concrete being the most widely used material globally as recorded by [5] has an estimated annual production of about 20 billion tons higher than any other material in the world. It is specifically considered to be the key to civil engineering. Ordinary concrete constitutes of cement, sand, gravel and water. However, as reported by [6] additives and admixtures are also sometimes added to the mixture to develop some special properties which are impossible to obtain with ordinary concrete alone. Apart from cement, all the other constituents of concrete are naturally and easily available and to a great extent, cement itself is also an easily accessible material.

On the setting of fresh concrete and its proper curing, the specimen hardens and gains considerable strength equal to or even harder than certain natural aggregates. For this reason, it is often referred to as man-made rock and has become the drive to its remarkable use [4]. Many supplementary cementitious materials (SCMs) as additives are however, sometimes added in concrete. Among these, silica fumes are very important industrial byproducts obtained from an electric furnace. The collection process involves the reduction of high purity quartz at high temperatures into silica vapors. These silica vapors are condensed at low temperature to small particles sizes known as silica fumes. The incorporation of silica fumes in concrete as supplements makes it denser, improves bonding and enhances resistance to chemical attacks [7]. Steel is an iron-carbon alloy although, not every iron carbon alloy is steel. Steel recorded by [8] refers to iron carbon alloy possessing carbon content up to 1.7%. Apart from carbon, other elements such as manganese, copper, silicon, nickel and molybdenum may also be found in minute quantities [9]. Outside iron, the other alloying elements are meant to improve strength, hardness and corrosion resistance of steel. Paints or coatings are normally used in construction to

Emmanuel Emem-Obong Agbenyeku is a research student at the University of Johannesburg, South Africa (phone: +27 11 559 6396; e-mail: emmaa@uj.ac.za).

Edison Muzenda is Head of Environmental and Process Systems Engineering Research Unit, Department of Chemical Engineering, University of Johannesburg, South Africa (phone: +27 11 559 6817; e-mail: emuzenda@uj.ac.za).

Innocent Mandla Msibi is Executive Director of the Research and Innovation Division, University of Johannesburg, South Africa (phone: +27 11 559 6280; e-mail: mimsibi@uj.ac.za).

protect surfaces from harmful weathering effects and for aesthetics. Different substances as noted by [10] constitute paint i.e., base, vehicle or binder, solvent or thinner, drier and coloring pigments. For instance, lead or aluminium is used as base; resins are used as vehicle or binder; oil or water is used to adjust the viscosity; lead or cobalt is used as drier. As such, where does the need for nanotechnology feature, in light of these numerous materials already in useful existence. The paper therefore emphasizes the relevance of nanotechnology towards the sustainable growth and development of the construction industry. Thus, introducing and pinpointing current applications of important nano building components presently in use alongside its merits and demerits thereof.

II. Importance Of Nanotechnology To Industries

Before the discovery of graphene, steel was considered the strongest construction material. According to ASTM A-36 as recorded by [11] steel has density of 7.85g/cm^{-3}, yield strength of 250MPa and ultimate strength of 400-550MPa. Graphene is now known to be stronger than steel as well as the thinnest material ever created even though it consists of only a mono layer of carbon atoms arranged in a honeycomb-shaped lattice. The atom lattice of a graphene is arranged in a hexagonal pattern weighing only 0.77g/m^2 [12]. Currently, graphene is used in the form of carbon nano tubes (CNTs) or carbon nano fibers (CNFs). CNTs are formed by the arrangement of graphene atomic scale wire mesh in cylindrical shapes. In the case of CNFs, they are made by the arrangement of graphitic carbon atoms in the form of plates with one placed over the other. The characteristics of graphene are not limited to its light weight but also possess strength about 100 times more than steel of similar thickness. It supersedes copper as observed by [12] in terms of heat and electricity transfer and has special optical and mechanical properties. In construction materials, engineers are ever interested in density, durability and strength. In actual sense, higher strength is usually associated with higher density, which in turn increases the dead weight of a structure. Graphene has tremendous potential to be the answer to future engineering demands, particularly, in construction industries due to its low density and outstanding strength properties. The importance of nanotechnology is not just limited to graphene, CNTs and CNFs.

Ongoing researches on the utilization of construction materials themselves in nanometers are gaining grounds. The introduction of nano cements is making the front lines in the building and construction market. For instance, the Bodome group of Austria has introduced nano cement on a commercial scale [13]. The current commercial cement particle varies in size from 1-100 micrometers as recorded by [14] and it is believed that finer particles (nano) have larger surface area per unit volume, which is very important in cement and concrete technology. Large surface area of binder results in higher early and final strength due to faster and more effective hydration reactions [15]. Several new cement composites are also presently developed by incorporating titanium (TiO_2), silica (SiO_2), clay and alumina (Al_2O_3) particles of nano sizes into them [1]. Also, nano paints are being developed that extensively improves the resistance of the paints and coatings against aggressive environments and the elements. Paints containing nano titanium and CNTs have been found as reported by [16] to be very effective against the negative impacts of industrial pollutants and fumes from car exhausts. The importance of nanotechnology, particularly, in the advancement of engineering works cannot be overemphasized. Nevertheless, a few vital nano materials developed and circulated for the benefits of construction industries in recent past are highlighted herein.

III. Nano-Materials Utilized Currently In Construction Industries

A. Carbon nano tubes (CNTs)

In recent times, CNTs are considered the strongest materials for engineering works. They have been recorded in [17] to have a modulus of elasticity of 1.8 Tetra Pascal, a tensile strength of 63GPa and a density of 1.4g-cm^{-3}. Hence, CNT has strength 120 times that of steel and is a much lighter material. Algae and barnacles have been found not to grow on paints containing CNTs. Thus, paints containing CNTs might successfully be applied in boats and ships. Also, because of its high strength, paints with much larger hardness and scratch resistance have been made. For example, the nano paint used on the Forth Bridge constructed in Scotland is said to only require repainting after a period 25years as the painting of the Forth Bridge as worlds heritage site by UNESCO was often considered an endless task since its commissioning in 1890 [18]. The latest repainting with nano paint will possibly allow another repainting only after a period of 25years. CNTs can be integrated in modern suspension bridges and cable-stayed bridges. Modern suspension bridges are made-up of roadways and cables of thousands of individual steel wires of 0.1 inch thickness. The CNTs having strength hundreds of times of that of steel can thus, be utilized in ropes of suspended bridges [19].

CNTs are also being included in concrete and a useful investigation in this regard was reported by [20]. Table I gives the strengths and densities of very common construction materials presently utilized in industry as against those of CNTs mentioned earlier. The scanning electron microscope (SEM) was used to show that CNTs occupied the pore spaces in concrete more effectively than other materials. The authors of the concrete test using CNTs recorded that CNTs can make concrete impenetrable to water and salts as such, greatly improving the durability of concrete. Also, a report by [21] stated that the addition 0.05% CNTs in foam concrete gives a lower density, increased compressive strength, lower thermal conductivity, lower average pore diameter and more homogeneous pore wall structure. Nonetheless, the dispersion of CNTs in concrete as observed by [22] is a highly complicated process due to the very high surface area of the nano particles as well as the Van der Waals forces contributing to binding effects. Where the dispersion CNTs is improperly done, an agglomerates is formed which destroys the effectiveness of the specimen. The works of [20] reported that CNTs can be effectively dispersed in concrete mixing water by using ultrasonic energy and a surfactant. While a proposition by [23] revealed a new method involving the attachment of CNTs directly on the surface of cement particles in concrete

matrix called a cement hybrid material or CMH. The authors stated that the CHM has two times the compressive strength and 40 times the electrical conductivity of the set slurry without CNTs.

TABLE I
*PROPERTIES OF NOMINAL CONSTRUCTION MATERIALS

Materials	**Ultimate tensile strength (MPa)	Density (g-cm^{-3})	Elastic modulus (GPa)
Glass ware	70	2.6	50-90
Timber	1-10	0.54-0.7	16
Aluminium	40-50	2.7	70
Steel	550	7.8	200
Limestone	5-8	2.7	15-55
Normal concrete	2-5	2.4	25

*[24] **Perpendicular to grain

B. Carbon nano fibers (CNFs)

Carbon nano fibers (CNFs) as recorded by [25] are graphene layers arranged as stacked cones, cups or plates. The wrapping of graphene layers into perfect cylinders is therefore referred to as CNTs. An investigation by [26] showed how an optimum concentration of CNFs was determined for use in concrete. It was observed to improve compressive strength as well as electrical properties of the tested specimens. CNFs are therefore, considered to be more effective than CNTs since their stacked structure exposes edges of increased surface area and better bonding characteristics. CNFs are however, comparatively easily formed and more cost effective than CNTs thereby, making them more attractive and affordable over CNTs for construction purposes. De-icing salts poured in snowy areas to melt the ice on roads are basically responsible for corroding the reinforcement steel bars buried in the concrete. CNFs have shown high heating capacity at low voltage, high electrical conductivity and resistance to corrosion since the inception as electrical resistive de-icing systems with the CNF being regarded as the heating element. This suggestion was first brought to the frontlines with the idea that CNF-reinforced concrete also called self-heating concrete is a thermally conductive product. The material is integrated with a resistive CNF paper and the paper is linked to an electric grid. The grid is responsible for converting electrical energy into heat while the heat is transferred to the surface which consequently melts the snow.

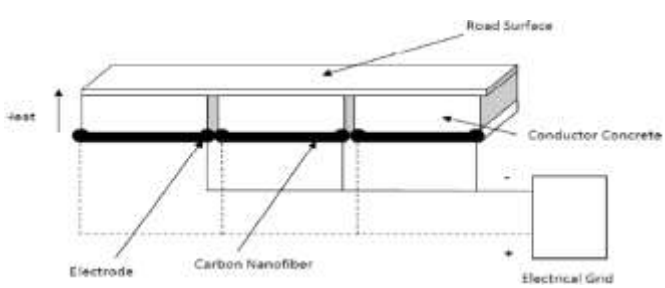

Fig. 1 Mechanism of a self-heating concrete system [24]

A diagrammatic expression is given in Fig. 1 as per [24] showing the self-heating mechanism of CNF-reinforced concrete system with the system completely eliminating the total reliance of heavy equipments and de-icing salt for removal of snow from roads. With respect to the investigations by [27] a physico-finite element model was prepared to assess the performance of the proposed system which claims that the system can effectively be used to de-ice snow covered concrete pavements. Nonetheless, the authors suggested that the system required in-situ evaluation for effective validation reasons.

C. Nano silica and Micro silica fumes

Micro silica fumes are introduced into concrete to satisfy certain purposes such as; serving as void fillers, increasing resistance against chemical attacks as well as decreasing its alkalinity. Hydration reaction occurs when Cement and water is mixed. A cement particle constitutes of four chemical compounds namely; Tricalcium sulfide (C_3S), Dicalcium sulfide (C_2S), Tricalcium aluminate (C_3A) and Tetracalcium alumino-ferrite (C_4AF) [6]. The reactions expressed in (1) and (2) show the hydration of the first two compounds- C_3S and C_2S with water which forms a gel of calcium-silicate-hydrate (CSH) and calcium hydroxide (CH) often called Portlandite with the release of heat.

$$C_3S + H_2O \rightarrow CSH + Ca(OH)_2 + Heat\uparrow \quad (1)$$
$$C_2S + H_2O \rightarrow CSH + Ca(OH)_2 + Heat\uparrow \quad (2)$$

On one hand, the CSH gel is of high bond and quite responsible for strongly binding the concrete particles together. On the other hand, Portlandite leaches out in water as a soluble product which also is a weak link between the concrete constituents. The incorporation of silica particles into concrete mix transforms the weak CH into a stronger CSH. The fumes of silica improves the properties of concrete by: (i) having the fines clog the voids between the cement particles and the voids between cement particles and aggregates and (ii) initiating a pozzolanic reaction with CH to form the CSH gel product thereby, heightening the binding quality and lowering the capillary and porosity of the concrete specimen [28]. Hence, it has been well documented that silica fumes improves the strength of concrete and produces a more homogeneous and denser product. The silica fumes in question simply refer to the micro particles by virtue of their sizes, fineness and total surface area. Nevertheless, through electron microscopy measurements the effect of silica fume on concrete properties has to a great extent been successfully proven [28].

It was however, believed that the nano silica particles will behave more effectively if used in place of micro silica fumes. Various works in recent past integrated nano silica particles in concrete and recorded up to 70% concrete compressive strength increase and 7.5% concrete bending tensile strength increase. Also, a 21.5% increase in splitting cylinder tensile strength of concrete at 28days and 13% increase in compressive strength at 91days have been recorded. An intriguing observation from documented works was that while normal concrete (set as the reference specimen) revealed no improvement in compressive strength beyond 28days, the nano silica concrete had a 15% strength increase from 28-91days. A diagrammatic representation of the transition of concrete from sizes in millimeter to nanometer is shown in Fig. 2.

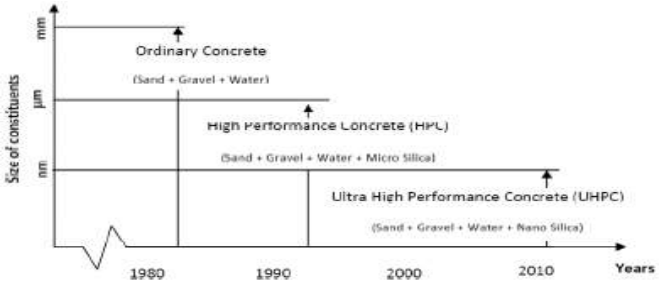

Fig. 2 Transition of concrete sizes in millimeter to nanometer [24]

Furthermore, considerable advancement in nano silica concrete in relation to strength improvement, refinement of pore structure and densification of interfacial transition zone were reported by [29] which was explained to be resultant of the large surface area of nano-silica particles.

D. Nano food-based additives for concrete

Corrosion of steel buried in reinforced concrete has over time remained a major engineering challenge. Huge amounts have continually been invested towards renovation and rehabilitation of deteriorating structures attacked by chloride-induced-corrosion. In the United States- National Institute of Standards and Technology (USA-NIST) concretes integrated with nano food-based additives are speedily gaining grounds. The method initiated is called Viscosity Enhancers Reducing Diffusion in Concrete Technology (VERDiCT). It is claimed that the viscosity of concrete pore solution can be enhanced with the incorporation of nano additives. This is made possible by slowing down or completely preventing the penetration of substances known for triggering steel rust/corrosion [24].

E. Fibers reinforced concrete of nano-layered oils

Concrete reinforced with fibers is a special concrete type having short discrete synthetic or natural fibers integrated in them. Some important fibers utilized include; steel, polypropylene, glass and carbon [24]. As reported in [24] Engineered Cementitious Composites (ECC) is a fiber reinforced concrete type. It is sometimes called a bendable or flexible concrete. ECC was invented in the USA- University of Michigan. It is another of nanotechnology's recent impact in concrete engineering technology. It is known that the conventional concrete is highly rigid and brittle and has a strain capacity of only 0.1%. The ECC however, has been claimed to bend like metal and as a special type of fiber reinforced concrete, the nano-slicked fibers embedded in the concrete allows for a strain capacity of more than 3% [24].

F. Nano titanium

Titania also called titanium oxide occurs naturally as an oxide of titanium and has the chemical formula TiO_2. Over decades, it has been in use as pigment in paints and coatings for reasons of whiteness, brightness and opacity. Titanium dioxide has been recorded to possess excellent ultraviolet (UV) resistant qualities as such, is used as sunscreen in cosmetics. The USA Food and Drug Association (FDA) declared micro and macro titanium safe for use in food, drugs and cosmetics [30]. Recent investigations nonetheless, as reported by [30] posits that nano particles of titanium dioxide may be toxic although, in decades past nano titania particles have remained in production.

Nano titania particles have been found to be stable, anticorrosive and possess photo catalytic properties [24]. Researchers have linked this photo catalytic activity to their high surface area and high reactivity. Nano-layers of titania are screed on glass of windows so they self-clean. Also as reported in [24] nano titania containing paint appears much easier to maintain and offers longer active life. Outside its use in paints, nano titanium particles have been incorporated in concrete called a self cleaning concrete or photo catalytic concrete. It is also known as smog eating concrete as it is a green concrete due to its environmental pollution self cleaning characteristics. Nano photo catalytic concrete can be applied in areas of environmental pollution cleansing and self disinfecting [24]. The merits of using solar power, harvested rain and runoff water has triggered new eco-friendly building materials. In the presence of light, [24] reported that TiO_2 disintegrates organic pollutants into harmless CO_2 and water. The reaction involved in this mechanism is presented in Fig. 3.

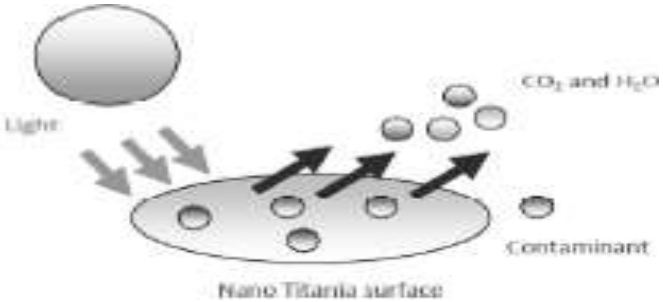

Fig. 3 Photo catalytic mechanism in nano titania [24]

Products of the reaction are then easily removed by rain or simply by rinsing thus, leaving buildings cleaner and aesthetically appealing. Photo catalytic concrete was first commercially introduced by an Italian company called Italcementi. A major benefit of utilizing TiO_2 as recorded in [24] is that UV light is required to activate photo catalytic processes which initiate the killing of bacteria and viruses as such; visible light absorbing photo catalysts with $Ag/AgBr/TiO_2$ has proven to kill germs more successfully.

IV. Dangers Associated With Utilizating Nano Particles

A number of merits on the utilization of nano particles have been highlighted. However, there are a handful of dangers with severe negative impacts associated with the wrong use and subsequent exposure to nano particles. Due to limited resources, the paper does not elaborately detail the dangers associated with nano particles. Few demerits are nonetheless mentioned to include: nano particles having high fineness as such are highly air and waterborne; this can lead to severe health conditions when the nano particles in question are particularly considered toxic as was recorded in [24]. As already mentioned, since nano titania particles can be of high toxicity according to USA health department [30] it is pertinent to address the health issues related to this recent and fast growing technology before its application becomes completely effused into societies. However, it is clear that the

engineering and technology involved in this recent area can incredibly benefit the human society if completely understood and can be safely harnessed/exploited.

V. Conclusions

A branch of chemical and material science dealing with nano particles was recorded herein. The paper emphasized on recent developments regarding the involvement of nano-materials in active areas of the construction industry in present times. The pertinence of nanotechnology towards sustainable growth and development of the industry has thus, become a global interest. From the points raised in this paper the following conclusions were reached:

- That the ultra high strength concrete, photo catalytic concrete, self-heating concrete, bendable concrete and concrete containing CNTs are major developments.
- That nano silica has become an effective substitute for micro silica/silica fumes in concrete giving it tremendous improved characteristics.
- It has been brought to knowledge that nano TiO_2 via photolytic effects can be used as an effective way of reducing contaminants, increasing human and environmental safety.
- Photo catalytic concrete can keep structures over decades looking new and aesthetically pleasing and as such is termed a green concrete.
- Various contaminants like algae and barnacles cannot grow on CNT-containing nano paints as such, can drastically reduce cost and saves time on repainting marine structures.
- The spread of germs can be reduced in laboratories and hospitals as well as improve urban air quality. It is therefore recommended that; related health concerns to the use of nano materials must be intensely investigated such that precautionary measures and remedies are put in place.

In summary, nanotechnology is seen to have tremendous potentials in construction industries for sustained growth and development of the built and natural environment. For instance, germ-free laboratories and hospitals, waterproof buildings, urban environmental protection etc., have been made possible through the utilization of nano materials. The investigation for various applications of nanotechnology to build up novel building materials is generally on the rise and has become clear that the science and engineering involved in the use of this material towards economic benefits is endless.

Acknowledgment

The Authors appreciate the University of Johannesburg where the study was done.

References

[1] Gopalakrishnan K. 2011. Nanotechnology in Civil Infrastructure: A Paradigm Shift (Springer, USA). http://dx.doi.org/10.1007/978-3-642-16657-0
[2] Fahlman B.D. 2007. Materials Chemistry (Springer, Germany). http://dx.doi.org/10.1007/978-1-4020-6120-2
[3] Sardar R., Funston A.M., Mulvaney P. and Murray R.W. 2009. Langmuir 25: 13840 http://dx.doi.org/10.1021/la9019475.
[4] Khitab A. 2012. Materials of Construction (Allied Books, Pakistan).
[5] Maarten A.T.M., Broekmans and Herbert P. 2013. Applied mineralogy of cement and concrete, ed. (Reviews in Mineralogy and Geochemistry, Mineralogical Society of America, Vol. 74).
[6] Neville A.M. 2011. Properties of Concrete (Pearson Education).
[7] Khitab A., Arshad M.T., Awan F.M. and Khan I. 2013. International Journal of Sustainable Construction Engineering & Technology 42:33.
[8] Allen E. and Iano J. 2011. Fundamentals of Building Construction: Materials and Methods (John Wiley and Sons).
[9] Adams K. 2009. Pocket Book of Steel (Corus Automotive, University of Warwick, UK).
[10] Freitag W. and Stoye D. 2008. Paints, Coatings and Solvents (John Wiley and Sons).
[11] Harvey P.D. 1982. Engineering Properties of Steel (ASTM International, USA).
[12] Thostenson E.T., Zhifeng R. and Chou T.W. 2001. Composites Science and Technology 61:1899 http://dx.doi.org/10.1016/S0266-3538(01)00094-X.
[13] http://www.bodome-group.com/nct-nanocement-technology.html
[14] Ferraris C.F., Hackley V.A. and Aviles A.I. 2004. Cement, Concrete, and Aggregates 26:1 http://dx.doi.org/10.1520/CCA12295.
[15] Popovics S. 2002. Concrete Materials: Properties, Specifications and Testing, (William Andrew Inc., Norwich, USA).
[16] Husken G., Hunger M. and Brouwers H.J.H. 2009. Building and Environment 44:2463. http://dx.doi.org/10.1016/j.buildenv.2009.04.010
[17] Saito R., Dresselhaus G. and Dresselhaus M.S. 1998. Physical Properties of Carbon Nano tubes, ed. (World Scientific).
[18] Ramsden J. 2009. Essentials of nanotechnology, (Free Book available at Bookboon.com).
[19] Makar J.M. and Beaudoin J.J. 2003. In: Proc. 1st International Symposium on Nanotechnology in Construction (Scotland), pp. 331.
[20] Konsta-Gdoutos M.S., Metaxa Z.X. and Shah S.P. 2010. Cement and Concrete Composites 32:110. http://dx.doi.org/10.1016/j.cemconcomp.2009.10.007
[21] Li H., Xiao H., Yuan J. and Ou J. 2004. Cement and Concrete Research 34:435. http://dx.doi.org/10.1016/j.cemconres.2003.11.007
[22] Ferro G., Tulliani J., Musso S. and Cassino F.R. 2011 Giugno 13:49.
[23] Nasibulin A.G., Shandakov S.D, Nasibulina L.I., Cwirzen A., Mudimela P.R., Habermehl-Cwirzen K., Grishin D.A., Gavrilov Y.V., Malm J.E.M., Tapper U., Tian Y., Penttala V., Karppinen M.J. and Kauppinen E.I. 2009. New Journal of Physics 11:083043. http://dx.doi.org/10.1088/1367-2630/11/2/023013
[24] Anwar K. and Muhammad T.A. 2014. Rev.Adv. Mater. Sci. 38:181-189.
[25] Jacobsen R.L., Tritt T.M., Guth J.R., Ehrlich A.C. and Gillespie D.J. 1995. Carbon 33:1217 http://dx.doi.org/10.1016/0008-6223(95)00057-K.
[26] Mullapudi T.R.S., Gao D. and Ayoub A. 2013. Magazine of Concrete Research 65:1081. http://dx.doi.org/10.1680/macr.12.00187
[27] Chang C., Ho M., Song G., Mo Y. and Li H. 2009. Journal of Smart materials and structures 18:127001.
[28] Bentz D.P. and Stutzman P.E. 1994. Cement and Concrete Research 24:1044. http://dx.doi.org/10.1016/0008-8846(94)90027-2
[29] Said A.M., Zeidan M.S., Bassuoni M.T. and Tian Y. 2012. Construction and Building Materials 36:838. http://dx.doi.org/10.1016/j.conbuildmat.2012.06.044
[30] Warheit D.B., Webb T.R., Reed K.L., Frerichs S. and Sayes C.M. 2007. Toxicology 230:90. http://dx.doi.org/10.1016/j.tox.2006.11.002