Chapter 10
Potential Environmental Impacts of Nanoparticles Used in Construction Industry

Annika Durve Gupta and Sonali Zankar Patil

Abstract Nanoparticles are ultrafine particles having a size ranging between 1 and 100 nm. Recently, nanoparticles have had various applications in fields like electronics; construction, manufacturing, cosmetics, agriculture, purification, and medicine have increased. Nanomaterials and nanocomposites have distinctive properties (physical and chemical), which have resulted in their use in the construction industry to facilitate innovative applications. The heavily used nanoparticles in the building industry are titanium dioxide, carbon nanotubes, silica, copper, clay, and aluminum oxide. The rising use of these nanoparticles has led to numerous adverse environmental effects. Nanoparticles of carbon, including fullerenes, nanotubes, metal oxides like iron and titanium, and natural inorganic compounds, along with asbestos and quartz, have shown to have toxic effects on the human health and environment. As the size of the particle is very small, they can pass through various mammalian and plant cell membranes and can also be absorbed in them. They can cause various inflammatory reactions and fibrosis in higher organisms and can exert an antioxidant and cytotoxicity effect on unicellular. Numerous respiratory and cardiovascular diseases are associated with continuous exposure to nanoparticles. In this chapter, we are dealing with the various nanoparticles produced and used in the construction industry and their deleterious effects seen in flora and fauna.

Keywords Construction industry · Cytotoxicity · Nanoparticles synthesis · Nanocomposites · Nanotoxicity

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J. A. Malik and S. Marathe (eds.), *Ecological and Health Effects of Building Materials*,
https://doi.org/10.1007/978-3-030-76073-1_10

10.1 Introduction

Richard P. Feynman, a physicist, gave the notion of nanotechnology in 1959, in his famed address, “There’s Plenty of Room at the Bottom”, at the American Physical Society at the California Institute of Technology (Feynman 1960). The opinions put ahead by Feynman went unobserved until Norio Taniguchi (1974), who coined the term “Nanotechnology” at the International Conference on Production Engineering (Taniguchi et al. 1974). Drexler defined nanotechnology as the production of materials having sizes between 1 and 100 nm (Drexler 1981). Hence, nanotechnology is quite old but has been explored now-a-days, has had a high demand in the last two decades. In fact, nanomaterials have been utilized unwittingly for thousands of years-nanoparticles of gold were used to stain glasses and helped cure several diseases. Researchers have increasingly been able to research and elucidate the physicochemical properties, which is shape- and size-dependent, of nanoparticles by using sophisticated and creative techniques (Rao et al. 2015; Rai et al. 2015; Abbasi et al. 2016; Giljohann et al. 2010; Pereira et al. 2015). Nanotechnology typically examines the matter that is manipulated at a nano-scale stage of between 1 and 100 nm. In various fields, the development of the nano sector has led to enormous growth viz. food and agriculture, pharmaceuticals, biotechnology, medicine, energy and the environment, material science (Kandasamy and Prema 2015). Nanoparticles can be characterized as particles with at least one dimension varying in diameter from 1 to 100 nm that can alter their physicochemical properties compared to their parent bulk matter. Due to their peculiar characteristics and innovative features, nanoparticles are widely used in various aspects of daily life and energy production. Nanoparticles have physical characteristics in materials science and biology, viz. Homogeneity, conductance and special optical characteristics that make them appealing. Nanoparticles can be synthesized from a variety of materials. Their properties preferably depend on their chemical composition and the size and/or shape of the particles (Kataria et al. 2019).

10.2 Synthesis of Nanoparticles

Two techniques are used to synthesize nanoparticles: the top-down approach and the bottom-up approach.

Several methods have been developed based on these two approaches (Fig. 10.1).

10.2.1 Top-Down Approach

This method includes the breakdown of large bulk material into particles of nano size. This can be achieved by different methods, i.e., Milling, method of attrition and wire technique for electro explosion. This is a fast method of production, but it uses

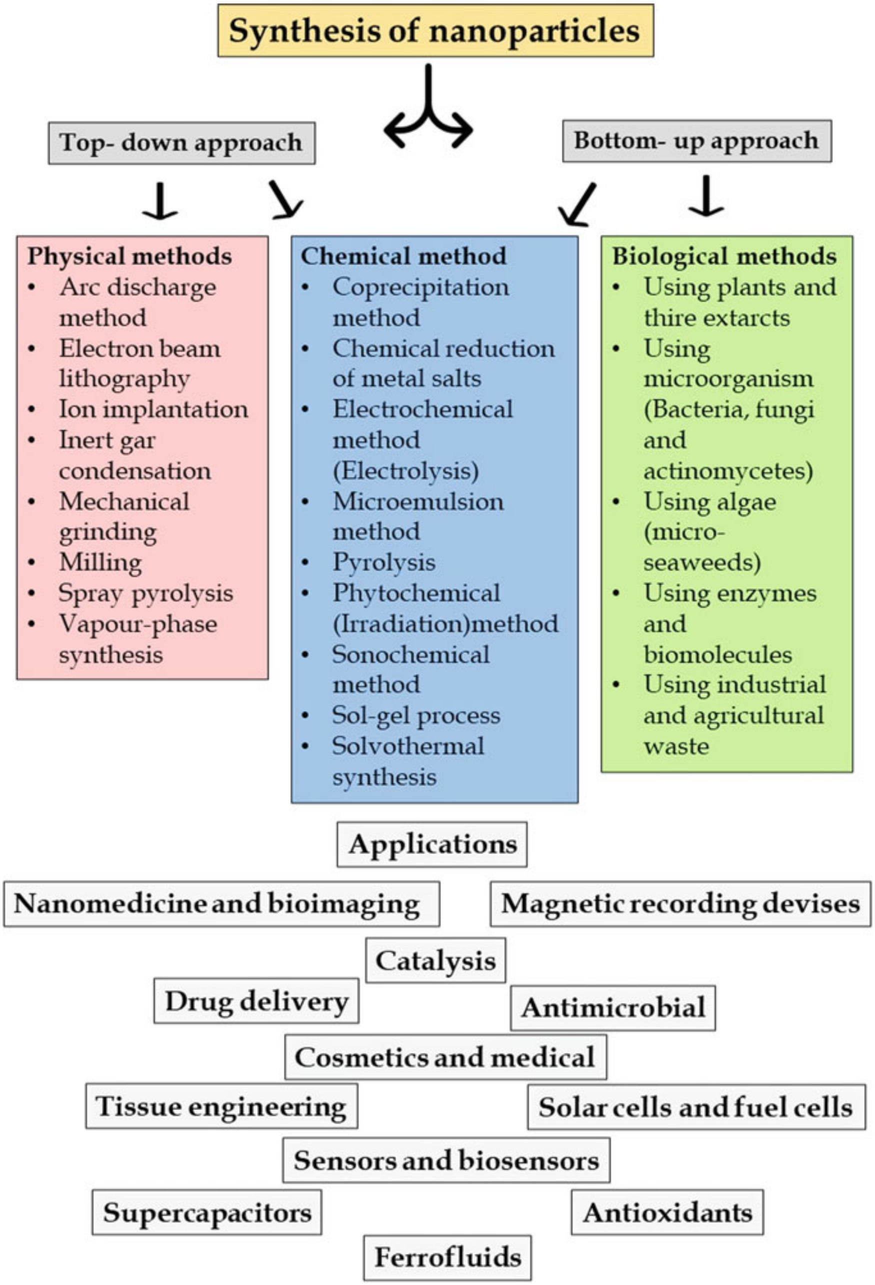

Fig. 10.1 Various methods (Physical, Chemical, and Biological) for nanoparticles synthesis and their applications in a variety of fields

more resources, so it is not ideal for large-scale production. Another downside of the top-down method is surface structure defects that have a huge influence on the physical and other properties of the produced nanoparticles (Thakkar et al. 2010).

10.2.2 Bottom-up Approach

The bottom method requires the creation of the material, molecular by molecule, atom by atom, and cluster by cluster. Physical forces acting on the nano structure are used during the process of construction to combine the particles into a larger one. For synthesis of complex nanostructures, a bottom-up approach is recommended as this approach can control the particle size resulting in good optical, electronic, and other properties (Doyle and Glass 2010). Thermal decomposition, Chemical vapor deposition method, solvothermal method, templating method, hydrothermal synthesis, pulsed laser ablation, combustion method, gas phase method, microwave synthesis, and traditional Sol-Gel technique are the various methods used to synthesize nanomaterials.

The environmental contamination caused by heavy metals limits the different physicochemical methods for the metal nanoparticles synthesis. It was therefore employed to synthesize nanoparticles through biological means. Biosynthesis of nanoparticles has the advantages of non-toxicity, manufacturing duplicability, easy scaling-up, and morphology that are well established. Microorganisms and plants have been used as reserves with considerable capacity for synthesizing nanoparticles. Till date, several microorganisms have been investigated for the synthesis of metal nanoparticles, including bacteria, fungi, and yeast, as well as plants. The various physical, chemical, and biological methods for the synthesis of nanoparticles with their applications were presented in Fig. 10.1.

10.3 Applications of Nanoparticles

Nanoparticles of gold are used for the targeted drug delivery like paclitaxel, methotrexate, and doxorubicin (Rai et al. 2015). They are utilized for the finding of tumour, angiogenesis, genetic disease, and diagnosis of various genetic disorders, photo imaging, and photo thermal treatment. Iron oxide particles of have been utilized for cancer treatment, hyperthermia, targeted drug delivery, repairing of tissue, labelling cells and cell organelles, and immunological assays, purification of biological fluids, imaging, and magnetically reactive drug delivery treatment (Khlebtsov et al. 2011; Huang et al. 2007; Iv et al. 2015). Nanoparticles of silver are used for various antimicrobial, anticancer, anti-inflammatory, and wound medication applications for different purposes (Ahamed et al. 2010). Various properties such as biocompatible, non-hazardous, self-purification, skin-friendly, antimicrobial, and dermatological activities are demonstrated by nanoparticles of titanium and zinc.

They have been used in various fields like cosmetic, biomedical, and as ultraviolet (UV)-preventing agents (Zahir et al. 2015; Ambika et al. 2015). Nanoparticles of palladium and copper are applied in certain polymers, batteries, plastics plasmonic waveguides, and optical restricting gadgets (Momeni et al. 2015; Nasrollahzadeh et al. 2015). Copper and palladium nanoparticles show antimicrobial activity against many pathogenic microorganisms. Metal nanoparticles have been used in the spatial study of different glycosphingolipids, nucleic acids, peptides, lipids, metabolites, and drug particles. The specific properties of nanoparticles make them more acceptable for the design of biosensors and electrochemical sensors (Peng et al. 2011). Nano sensors are designed for the recognition of algal and mycobacteria toxins, along with heavy metals in various sources (Selid et al. 2009). Nanosensors have been created by using nanoparticles for management of various hormones and for the sensing of viruses, crop pests, stress factors, and nutrient levels in the soil (Koren et al. 2015). In many biomedical applications, such as anticancer and antimicrobial applications, biological nanoparticles have been implemented. This is because biologically synthesized nanoparticles, particularly in biomedical applications, show greater efficacy compared to physicochemical nanoparticles (Singh et al. 2016).

10.3.1 Use of Various Nanoparticles in Construction Area

In civil engineering, the use of good building materials plays a very crucial role. Steel, concrete, bricks, stones, wood, glass, and many metallic elements are the key building materials (Khitab 2012). The oldest resources used by primitive humans to build refuge against natural catastrophes and wild animals were stone and timber. Like the evolution of all other species on the planet, the raw material of construction also passed through an evolutionary course. As the modern-day giants in the construction industry, we now have concrete and steel. As the experience grew, engineers and researchers created brand new and smart materials. A recent and new scheme that surfaced at the end of the last centenary has been the utilization of nano technology and nano materials in civil engineering. The use of this new and modern technology has solved several of the construction industry‘s challenges. This is because of the nanomaterials’ higher strength and lower density.

The use of these nanomaterials is expanding in numerous fields, such as automotive, biomedicine, electronics, construction, and robotics due to their unique mechanical, chemical, electronic, and optical properties. Currently, however, the use of nanotechnology and nanomaterials in civil engineering is much less significant, especially in the construction sector (Ge and Gao 2008; Li 2004; Irie et al. 2004). These nanomaterials are mostly used to give sturdier physical composites, lighter structure, improved cement like material properties, low maintenance coating, better-quality pipe joining materials, upgraded heat and sound insulation, better glass reflectivity, water repellents, self-cleaning and antifogging surfaces, ultraviolet light protector, nanosized building safety and structural health monitoring sensors and solar cells (Daniyal et al. 2018) (Table 10.1).

Table 10.1 Several nanomaterials used in the construction Industry

Nanomaterials	Base raw material	Potential advantages	References
Zirconium oxide (ZrO_2)	Concrete and cement	Tensile strength is boosted	Nazari and Shadi (2010), Nazari et al. (2010c)
Silver (Ag)	Paints	Shows antimicrobial properties	Kumar et al. (2008)
Carbon nanotube (CNT)	Concrete and cement	Tensile strength and stability are improved	Małgorzata (2014), Becher (1991), Saafi and Romine (2005), Song et al. (2008), Zhang et al. (2006), Nochaiya and Chaipanich (2011), Chaipanich et al. (2010)
	Ceramics	Thermal and mechanistic properties are enhancement	Becher (1991)
	Nano electrical mechanism systems	Health assessment of structures are carried out in real time	Saafi and Romine (2005), Song et al. (2008)
	Solar cell	Electron mediation efficient	Girishkumar et al. (2005)
Silicon dioxide (SiO_2)	Concrete and cement	Tensile strength and stability are enhancement	Zhang and Li (2011), Hussain and Sastry (2014), Ye et al. (2007)
	Glass	Antireflective and heat isolation	Rana et al. (2009)
Titanium dioxide (TiO_2)	Solar cell	Production of non-utility power	Serpone and Pellizzetti (1989)
	Glass	Antifogging, hydrophilicity, fouling resistance	Ruot et al. (2009), Guerrini (2012)
	Concrete and cement	Self-cleaning, rapid hydration and mechanical strengths are improvement	Mohseni et al. (2015), Ruot et al. (2009), Guerrini (2012)
Calcium carbonate ($CaCO_3$)	Concrete and cement	Tensile strength is boosted	Sato and Diallo (2010), Kawashima et al. (2013), Shaikh and Supit (2014)

(continued)

Table 10.1 (continued)

Nanomaterials	Base raw material	Potential advantages	References
Copper oxide (CuO)	Concrete and cement/steel	Tensile strength and stability are improved, improved weldability and resistance to corrosion by steel	Nazari and Shadi (2011), Nazari et al. (2011)
Aluminium oxide (Al_2O_3)	Concrete and cement	Tensile strengths are boosted	Arefi et al. (2011), Zhenhua et al. (2006)
	Asphalt concrete	Increased serviceability	
Zycosoil	Asphalt concrete	Increased weakened life, higher compaction	Sarkar et al. (2014)
Chromium oxide (Cr_2O_3)	Concrete and cement	Tensile strengths are boosted	Nazari and Riahi (2011a, b)
Ferric oxide (Fe_2O_3)	Concrete and cement	Tensile strengths and stability are improvement	Nazari et al. (2010a, b), Yazdi et al. (2011)
Clay nanoparticles	Bricks mortar	Heightened compressive strength	Daniyal et al. (2018)

The development of laboratories and hospitals free of microorganism, water-resistant homes, metropolitan environmental safety has resulted because of the use of nanoparticles in construction (Lee et al. 2010). Cement nanomaterials have been applied, resulting in a substantial decrease in cementitious composite preliminary setting time as well as finishing setting time. The broad specific surface areas, the larger number of highly unstable and active atoms on the surface, speed up the reaction for hydration of cement and eventually minimize the setting time needed for the cement. The incorporation of nanomaterials also substantially decreases the workability of composites of cement. The substitution of cement with nanoparticles has caused the total surface area to increase. Therefore, more water for lubrication is needed to make wet the particles. The support of high-quality plasticizers and additional cement materials such as silica fume, rice husk ash, fly ash, and nanoparticles have overcome this problem (Daniyal et al. 2018). With the use of sufficient nanomaterial concentrations, the tensile strengths and stability properties of cement composites are dramatically increased. The addition of nanoparticles to it, has produced ultra-high-strength concrete, photocatalytic concrete, self-heating concrete, bendable concrete, and concrete containing CNTs. Instead of micro silica particles, Nano Silica Concrete has nano silica, which has led to higher initial and final compressive forces, greater workability, and lower absorbency. In addition, in the concrete, higher tensile strength and segregation resistance were also seen. The new concrete, Ultra High Strength Concrete, has many advantages viz. the column sections in buildings and amount of steel reinforcement in concrete could be reduced (Li 2004). The calcium nitrite-impeded as well as graphene and nano-TiO_2-mixed cement slurry coating showed significant level of corrosion inhibition of when associated with uninhibited systems (Daniyal et al. 2018).

In asphalt cement, a 5% inclusion of nano-aluminium oxide (Al_2O_3) was tested to verify the effect of the modifier on asphalt cement. This addition demonstrated good high temperature resistance and improved the material's serviceability (Mubaraki et al. 2016; Fang et al. 2016; Mohajerani et al. 2017). Moisture damage is a major obstacle around the world due to the malfunction of the layers made up of hot mix asphalt due to the penetration of water into the sidewalk system, resulting in a loss of hardness, endurance, and strength (Nejad et al. 2012; Jin et al. 2019). Zycosoil has been used to test the asphalt concrete properties when mixed with zycosoil as an anti-strip agent (Sarkar et al. 2014). Owing to the rise of the filler and the reduction of air spaces in the asphalt blend, the fatigue life has been improved. In addition, due to the alteration of the aggregate surface, superior compaction because of the asphalt blend have been obtained (Nejad et al. 2012).

An Investigation to verify the effect of nano-clays on earth bricks was performed out by Niroumand et al. (2013). Nano-clays are nanoparticles coated with mineral silicates, and the utilization of bricks embedded with various nanoparticles is dictated by the chemical composition of the brick. The results showed that a nano-clay addition of 5% can yield a compressive strength of 4.8 times that of regular clay bricks (Niroumand et al. 2013). As compared to standard clay bricks, the nano-clay modifier is the most ecological balanced material. The efficacy of various shielding coatings on bricks was tested by Stefanidou and Kazou (2016) the physical properties of each solution were checked. 1–1.5% silica nanoparticles were modified by addition of silane/siloxane, linseed oil, and alka siloxane. Silica nanoparticles and alkosiloxane have been shown to be the highly efficient method to secure bricks that have shown high endurance to water absorption and a major increase in toughness.

In the building area, timber is also used. A timber coating was made, using silica nanoparticles (SiO_2) and alumina which were integrated with hydrophobic polymers (Mohamed 2015). This coating created an invisible layer, confining water, soil, oil, algae and dust-resistant properties on the surface of the timber. It also provides UV protection and retained surface quality (Mohajerani et al. 2018). Medium density fibreboard (MDF) is a wood processing commodity composed of a synthetic resin merged with fine lignocellulosic fibers that are subjected to stress and high temperature to form panels (Kumar et al. 2013). The method is considered expensive, so reducing the press time would diminish the cost of production and boost the ability of production. The effect of nano-aluminium oxide (Al_2O_3) on the heat transfer step of MDF during the hot-pressing process was studied by Kumar et al. (2013). The results showed an increase in the mechanical and physical traits of MDF panels due to the improvement in heat transfer.

Uneven surface may lead to increasing stress and, hence, cracking due to fatigue in traditional steel; however, surface unevenness can be minimized with the addition of nanoparticles as a modifier and, therefore, cracking can be lowered (Tiwari and Chowdhury 2012). In addition, studies have shown that by strengthening the steel microstructure, the effects of embrittlement of hydrogen and the intergranular cement process are minimized (Mohamed 2015). The effect of colloidal nanoparticles of copper as an enhancer for steel corrosion resistant coatings was studied by Hegazy et al. (2013).

Additional protection of window glass, pavement, walls, and roofs are made by integration or layering with SiO_2 and TiO_2 nanoparticles. The windows could be made fireproof by using silica nano layers which are placed between two glass panels (Mann 2006). Silica nanoparticles added to the windows help monitor external light by acting as an anti-reflection coating and contribute to energy efficiency by having an effect on air conditioning (Rana et al. 2009). TiO_2 is photoactivated to generate reactive oxygen species (ROS) by exposing them to UV light indoors with sunlight, allowing successful eradication of bacterial biofilms and dirt attached to the windows (Irie et al. 2004; Paz et al. 1995). TiO_2 nanoparticles layered on footpaths, roofs and walls serve as an anti-fogging mediator to keep surfaces dirt free when exposed to solar radiation and avoid the accumulation of hydrophobic dust on windows (Zhu et al. 2004; Irie et al. 2004).

In paint, silver nanoparticles can be combined with the paint, to destroy pathogenic microorganisms and provide surfaces (e.g., hospital walls) with antimicrobial properties (Kumar et al. 2008). Due to its photoactivity under UV lighting, titanium dioxide (TiO2) acts as a biological killing agent and can confer antibacterial and antifungal properties on surfaces of the wood (Goffredo et al. 2017). Stronger types of steel can be created by adding nanoparticles to steel coating paints when they are used as concrete building reinforcing bars. These bars are referred to as multi-structural micro-composite formable (MMFX) steel, which is favoured over conventional steel because of its corrosion resistance and robust properties (Mohamed 2015).

In construction buildings, micro and nano-scale sensors and actuators are inserted for precise actual-time observation of structural/material destruction and conditions (e.g., stress, wear, corrosion, and cracking) and environmental circumstances (e.g., temperature, moisture, and smoke) (Saafi and Romine 2005; Song et al. 2008). As the system senses strain inputs, CNT/polycarbonate nanocomposite sensors produce brief alterations in electrical resistance, providing a prompt indication of potential structural damage (Zhang et al. 2006). The extraordinary electron shuttle properties of CNTs and C60 fullerenes are used to improve the efficiency of solar and fuel cells generating renewable energy (Girishkumar et al. 2005; Brown and Kamat 2008).

10.4 Health Effects of Nanoparticles

Nanomaterials are used to improve several different product types (Royal Society 2004), and day by day, the marketing of goods using these specific properties of nanoparticles is growing. These same new features, however, have demonstrated new difficulties in recognizing, predicting, and treating possible harmful health impacts after coming in contact with them (Hood 2004). The extensive use of nanoparticles provides tremendous possibility for human contact and release in the environment. The massive advancement of technology and diverse applications has had an impact on health research and may cause environmental risk. The prospect of nanotechnology, like the development and use of genetically modified organisms, would be highly dependent on public acceptance of the risks and benefits of these nanoparticles. The study shows that in vitro conditions, along with high concentrations of nanoparticles, are highly poisonous to marine organisms, bacteria, and human cells. Also, non-toxic compounds may generally become dangerous at the nanoscale. According to particle physics, nanoparticles size allows them to stay suspended into the air, for days to weeks if released (Elliott 2011; Lidén 2011; Potera 2010). It is possible to inhale nanoparticles, which would result in the accumulation of these particles in the animal or plant respiratory system. This can also result in the bioaccumulation of nanoparticles (Rizzello and Pompa 2014; Yang and Ma 2010; Diao and Yao 2009).

At various stages, nanoparticles may be released into the atmosphere accidentally or incidentally. Some nanoparticles may be counted as possible developing contaminants, growing fears about the related risks to public and environmental health, as their environmental release is presently not regulated. Nanoparticles may go through various alterations once in the environment, which alter their characteristics, effects, and destiny. Therefore, reporting on lifecycle exposure to nanoparticles is important for evaluating possible impacts on ecosystem and human health, as well as minimizing avoidable risks.

Since recent years, there are many innovations in nanotechnology that have created angst regarding the existence, spread, outcome, and transport of nanoparticles into the environment. Nanoparticles are used in an array of manufacturing and civil processes, biomedical functions, consumer goods, food, and drug delivery systems, etc. due to which there is a wide spread of nanoparticles in the atmosphere. The volume of these nanoparticles has risen in the ecosystem, as they are released in the environment as a waste product or as a by-product of some manufacturing procedure, which has resulted in several worries regarding human health and the environment.

Two areas of nanoparticles are important here;

1. In a free shape, where nanoparticles either be discharged into the water or air during production or manufacturing incidents, or as a by-product of manufacturing waste and subsequently deposited in the water, soil, or plants.
2. If they are components of a processed material or commodity in a fixed form, they will eventually have to be reused or removed as waste.

For an extended period of time, nanoparticles emitted at the construction site remain in the air during which employees may be exposed to them. There are no suitable chemical management policies enforced in such areas. Staff inhale dust, which can lead to serious health problems, with the example of dust on worksites (Kumar and Morawska 2014).

10.4.1 Effect of Nanoparticles on Microorganisms

Nanoparticles used in the construction sites have unfavourable effects on the microbial population in the vicinity. These nanoparticles tend to utilize their antibacterial properties via a variety of methods (Aderibigbe 2017; AlMatar et al. 2017; Hemeg 2017; Bassegoda et al. 2018) (Fig. 10.2) such as;

1. Directly interacting with the microbial cell wall,
2. Formation of biofilm suppression,
3. Eliciting of innate and adaptive host immune responses,
4. Production of ROS, and
5. Generation of intracellular effects (e.g., binding with proteins and/or DNA).

The effects of various nanoparticles on microorganisms are shown in Fig. 10.2. Damage to the bacterial cell membrane happens when nanoparticles attach electrostatically to the cell wall and membranes of the bacterial, resulting in the modification of cell membrane potential, depolarization of the membrane, and loss of stability. This results in transport disparity, decreased respiration, cell lysis damage and/or, energy transduction and eventually death of the cell (Pelgrift and Friedman 2013). The most important element for the in vivo *and* in vitro cell-toxicity of nanoparticles is known to be Reactive Oxygen Species (ROS). They are produced indirectly by respiratory chain disruption or directly by the nanoparticles (Nathan and Cunningham-Bussel 2013). A ROS surge occurs due to extreme oxidative stress, which causes injury to all the macromolecules of the cell, resulting in peroxidation of lipid, protein modification, inhibition of enzyme, and damage to DNA and RNA. At high concentrations, ROS can lead to cell death and cause serious DNA damage and mutations at low doses

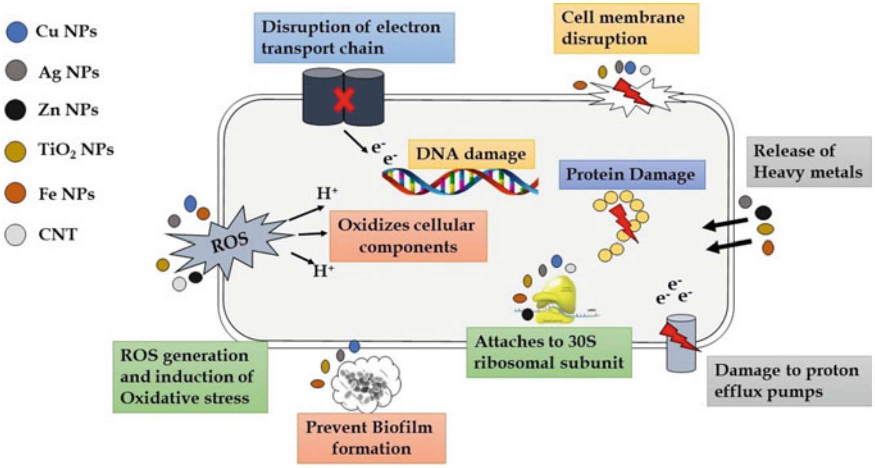

Fig. 10.2 Effects of various nanoparticles on microorganisms

(Pan et al. 2010; Wang et al. 2011). The harmfulness of nanoparticles is a photocatalytic reaction when the production of ROS is caused by visible or UV light. Many other impacts of nanoparticles consist of direct inhibition of vitalenzymes, initiation of nitrogen reactive species (NRS), and programmed death of the cell (Pelgrift and Friedman 2013; Huh and Kwon 2011; Hajipour et al. 2012; Belcher et al. 2011).

Such nanoparticles do not exert the same antibiotic mechanism of action, thus causing more damage. Both lipids and membrane proteins are destroyed by ZnO NPs, which can cause cell death. They result in the formation of hydrogen peroxide (H_2O_2), including Zn^{2+} ions and ROS, which damage the bacterial cell. Copper associates with groups of amines and carbonyls found on microbe's cell surfaces. ROS can be formed by greater concentrations of Cu^{2+} ions. TiO_2 NPs produce ROS, including hydroxyl radicals (·OH) and hydrogen peroxide (H_2O_2), in a photocatalysis phase on contact with UVA and near-UV irradiation (Ruparelia et al. 2008). MgX_2 NPs cause peroxidation of lipids in the microbial cell envelope by generating ROS. MgF_2 NPs can cause peroxidation of lipid and a decline in cytoplasmic pH, which may increase membrane potential (Lellouche et al. 2009, 2012; Belcher et al. 2011). Silver's antimicrobial activity is due to its Ag^+ ions. By binding to them, Ag^+ inhibits the microbe's electron transport chain, destroying RNA and DNA. It also prevents inhibition of cell division by the replication of DNA (Sondi and Salopek-Sondi 2004; Choi et al. 2008). Direct damage to cell walls appears to be the microbial toxicity mechanism of SWNTs, while MWNTs cause toxicity by oxidative stress (Kang et al. 2007, 2008a, b).

10.4.2 Effect of Nanoparticles on Plants

The plant system's interaction and absorption of nanoparticles is determined on the design of the nanoparticles, including the shape, size and amount used. The nanoparticles, which lie in the 40–50 nm size range, are able to easily penetrate the plant tissues. Through various mechanisms, nanoparticles interact with the system of plant roots. 2 nm size nanoparticles can be exogenously applied via leaves, which will traverse the cuticular pore into the stomata (Eichert and Goldbach 2008; Schwab et al. 2016).

Numerous possibilities have been suggested for the absorption of nanoparticles by plant cells. The data show that by binding to a transporter protein, all through the aquaporin, ion channels, or endocytosis via the formation of new pores, nanomaterials could reach plant cells, eventually ending up binding to an organic chemical inside the cell (Maine et al. 2001; Kurepa et al. 2010). In the case of CNTs, this mode of transmission of nanoparticles is mainly seen (Smirnova et al. 2012). Before being transported into the plants; the nanomaterials can produce complexes along with cell membrane carriers or root exudates. Reports show that plants take up most metal-based nanomaterials, including elements for which ion carriers have been recognized (Tani and Barrington 2005). As nanomaterials join plant cells, they can be moved via the plasmodesmata of the cell from one cell to another (Hauck et al. 2008).

At higher concentrations, the plants carry out the accumulation of nanoparticles which can result in an escalation in the activity of superoxide dismutase and catalase enzymes and a reduction in photosynthesis. Silver nanoparticles increase the shoot and root length when used at low intensity but reduce the length at high concentration. In root growth, biomass and root length, a reduction is seen. Broken epidermis and root caps have been found in some cases. Seed germination decreased along with shoot length was affected by different concentrations of silver nanoparticles, and a reduction in plant growth was observed. The reduced mitotic index resulted due to the higher concentration of silver nanoparticles. Cell division processes are disrupted by the silver nanoparticles, resulting in a mixed-up metaphase, chromatin bridge, several chromosomal splits, and eventually cell disintegration. In agricultural and grassland plants, DNA was damaged owing to the existence of copper oxide nanoparticles (Vannini et al. 2013; Krishnaraj et al. 2012; Fageria et al. 1990; Jasim et al. 2017).

Monodisperse particles of nano-zinc oxide inhibit root growth and inhibited chlorophyll synthesis, resulting in decreased photosynthetic effectiveness. When zinc nanoparticles were present, a decrease in germination and simultaneous suppression of root growth was seen (Ramesh et al. 2014; De la Rosa et al. 2013; Zafar et al. 2016). Nanoparticles of copper oxide lowered the chlorophyll content in plants. After the plants' exposure to copper ions and copper nanoparticles, lipid peroxidation was enhanced. Copper/Copper oxide (Cu/Cu_2O) nanoparticles via adsorption could obstruct water channels. The potential for radical penetration into onion roots could also be increased (Fiskesjo 1993; Geremias et al. 2010), which may result in disruption of the entire cell division stages and metabolism. The toxicity study of cobalt and zinc oxide nanoparticles showed that escalating concentrations of the nanoparticles results in the roots elongation inhibition as compared with control plants. The toxicity of nanoparticles of cobalt oxide could be because these nanoparticles can block the water channels through adsorption, while the zinc oxide nanoparticles penetrate drastically into the roots of the plant and destroy the whole metabolism and cell division stages. ZnO nanomaterials are one of the most toxic nanomaterials that could result in termination of root growth (Stella et al. 2010; Ma et al. 2009; Huang et al. 2002). Aluminium oxide results in decreased plant growth and development (Foy and Fleming 1982). Figure 10.3 shows the interaction of nanomaterials in the environment and plants.

Inhibitory effects on the development are seen by the presence of ferrous nanoparticles (Fageria et al. 1990). The surplus iron oxide (Fe_3O_4) amount as the magnetic nanomaterial caused various negative effects seen in growth of the plant. The level of chlorophyll was magnified at low fluid concentrations of Fe_3O_4 nanoparticles, whereas it was impeded at higher concentrations. Repressing effect was seen on the plantlets growth that resulted in the formation of brown spots on leaves at greater volumes of Fe_3O_4 nanoparticles (Stephan 2004; Laanbroek 1990; Hartley and Lepp 2008). Oxidative stress was the result of excess Fe_3O_4 nanoparticles, which impaired the rate of photosynthesis and a decreased metabolism rate. The oxidative stress caused by the accumulation of Fe_3O_4 fluid in the living plant's tissues (Hartley and Lepp 2008; John 1988; Bencana et al. 1998; Green and Etherington 1977). TiO_2 nanoparticles have a very small size due to which they have a tendency to form a

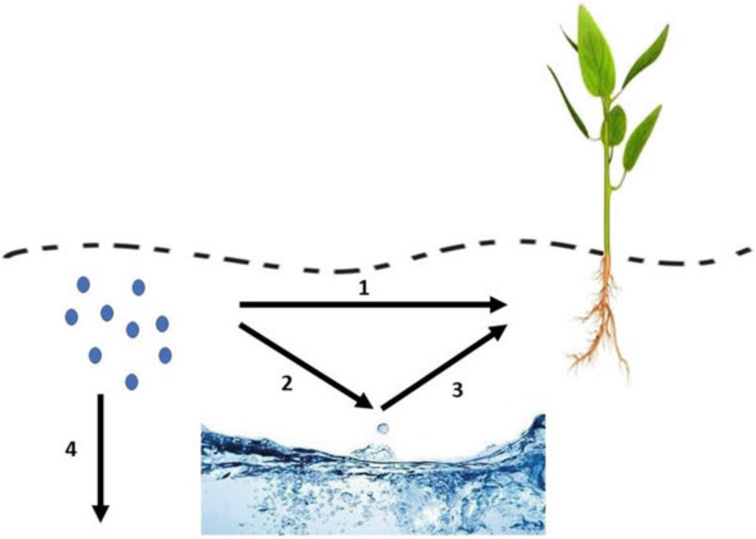

Fig. 10.3 Interaction of nanomaterials in the environment and plants; (1) plant root absorbed nanomaterials directly, (2) nanomaterials combined with water, (3) nanomaterials combined with water and transported to the plant, (4) nanomaterials remained in the soil

covalent bond with no-conjugate natural organic matter, move from one place to another, following the cells' and tissue specific circulation (Garcia et al. 2009; Feizi et al. 2012, 2013; Castiglione et al. 2011). Algal species, *Desmodesmus subspicatus* also showed toxic effects of TiO_2 nanoparticles (Hund-Rinke and Simon 2006). TiO_2 nanoparticles created ROS on contact with organisms or UV irradiation (Khataee et al. 2014; Larue et al. 2012; Dehkourdi and Mosavi; 2013). The phytotoxicity effect on cucumber, maize, carrot, cabbage, and soybean by uncoated and phenanthrene-coated alumina (Al_2O_3) nanoparticles was examined. The results showed that the root elongation was inhibited by uncoated Al_2O_3 nanoparticles at 2mgL^{-1} concentrations. The toxicity is shown to be maybe not nano-specified but may be owing to the suspension of nanoparticles of Al_2O_3. ZnO nanoparticles tend to penetrate the cells of the root and impede growth of the seedling (Blamey et al. 1983; Kollmeier et al. 2000; Yamamoto et al. 2001).

10.4.3 Effect on Animals and Humans

There are several distinctive properties that make it so promising for nanomaterials in construction. However, massive usage of the building industry can also produce unexpected effects on the human health and environment. Inhalation of nanoparticles during the coating, molding, compounding, and amalgamation process may cause

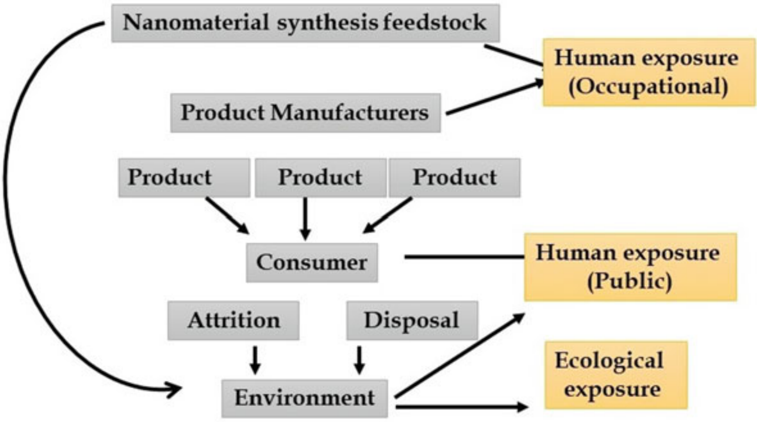

Fig. 10.4 Routes of exposure of nanoparticles

workers to experience many respiratory problems. A risk evaluation questionnaire on the effect of nano-TiO_2 proved that work-related exposure surpassed the normal limit only in the process of packaging. In some cases, nanomaterials exposure may also happen during manufacture and processing before integration into manufactured goods. During aqueous dispersal of CNTs and fullerenes, aerosolized carbon NPs can be produced through sonification, while airborne particles are released during weighing (Rahman et al. 2017). The release of some building nanoparticles can result in activities such as construction, repair, renovation, and demolition (Fig. 10.4).

Figure 10.4 shows the routes of exposure of nanoparticles. Nanomaterial wastes, from industrial processes or building and destruction activities, go through crushing procedure before they are transferred to the disposal unit which may cause their release in the ecosystem. Inhalation is a one of the crucial methods for nanoparticles spread through the body. This has caused an increase in anxiety regarding toxic pulmonary diseases. This is similar to asbestosis, where pleural fibrosis, lung cancer, and mesothelioma are caused by inhaled small crystalline fibers of asbestos (Donaldson and Seaton 2012). Workers were exposed to carcinogenic fibres for many years prior to the initiation of various regulation. This was partly due to the lack of knowledge of the health risks linked with asbestosis. Particles inhalation on building areas has been recognized as a health and safety issue. Studies linked to chronic nasal exposure in male mice were carried out and the results may be comparable with humans. Male mice were subjected to nasal inhalation installation of 1.25, 2.5, or 5 mg/kg TiO_2 nanoparticles for nine months. The outcomes showed a drop in body weight, inflammation and cell permeation, and tumour formation in mouse lung tissue, along with dysfunction of metabolism. Similar experiment was conducted out using nickel hydroxide, subjecting the mice to Ni $(OH)_2$ particles over several time intervals (Gillespie et al. 2010). The findings demonstrated the presence of inflammation of the lungs along with a different reaction varying on the length of the contact.

The rise in the number of polymorphonuclear leukocytes (PMN), lymphocytes and macrophages has aided in an inflammatory reaction (Gillespie et al. 2010).

Nanoparticles can penetrate the skin, gaining entrance into the body. Dermal absorption has been identified via various methods—transcellular, intercellular, and trans-appendageal via follicles of hair or sweat glands. This will also depend on the properties of the specific nanoparticles (Crosera et al. 2009). Dermal absorption is not given much importance in front of studies on inhalation exposure, and the evaluated threat is minimal due to the opinion that they are less permeable via the skin route (Crosera et al. 2009). Polystyrene nanoparticles were spread using vertical diffusion cells at intervals of 0.5, 1 and 2 h in a study conducted using porcine skin. Surface imaging experiments showed an accumulation in the follicular openings of smaller nanoparticles. It is important to carry out studies to determine if the particle will move through the skin at lesion, flexure, and wound sites (Crosera et al. 2009). Experiments have shown that ZnO and TiO_2nanoparticles were incapable of passing via the skin showing them to be safe to cutaneous exposure. Ag nanoparticles were found to enter via the skin but their capability to penetrate is yet to be studied. Their usage in dressings of various medical injuries may cause absorption via the skin, possibly causing damage to the internal organs (Crosera et al. 2009).

Nanoparticles of Ni, Pd, and Co are deemed to be more dangerous due to the high-level release of ions (Filon et al. 2015). Carbon nanotubes (MWNTs and SWNTs) of small sizes create a possible threat as they cause toxicity in the pulmonary system, like fibrosis, inflammation, and epithelioid granulomas in animals (Filon et al. 2015; Karlsson et al. 2008; Park et al. 2007; Reeves et al. 2008). SiO_2 NPs have been reported to exert carcinogenic activity. Exposure to nanosized SiO_2 causes lipid peroxidation and membrane damage on human lung cancer cells and induces tumour necrosis genes in rats (Lin et al. 2006; Donaldson and Seaton 2012; Buchanan et al. 1993; Oravisjärvi et al. 2014). Table 10.2 enlists various health ailments due to the presence of nanoparticles.

10.5 Conclusion

The utilization of nanoparticles in the construction/civil industry presents a number of prospects and challenges. In building, the use of nanoparticles can be used not only to enhance the materials and utilities properties, but also to conserve energy. This is particularly important as residential homes and commercial buildings that provide heating, air conditioning and lighting use a high percentage of all energy consumed. In order to have a greener construction industry, nanomaterials can also take part in the production process. This can happen when we use nanoparticles as a substitute for materials that are dangerous ecological pollutants, like mercury and lead. Prospects for energy savings involve enhanced heat management by using nanoparticles of silica in paint/coating and insulating ceramics that allow energy saving and nano-TiO_2-coated surfaces which are solar-powered and self-cleaning. The usage of Quantum dots and CNTs to increase the performance of energy transfer,

Table 10.2 Health implications of nanoparticles to the human body (Wiemann et al. 2017; Ahamed et al. 2010; Grande and Tucci 2016; Donaldson et al. 2000; Karlsson et al. 2008; Wickrath et al. 2017)

Nanoparticle	Type affected cell/Organ/System
C60 (water-stable colloid)	Absorbed by human keratinocytes; toxicity to human cell lines; peroxidation of lipid, stabilizes proteins
C60 derivatives	Cell death/necrosis; oxidative cytotoxicity; liver accumulation; sarcomas in mice and human cells, gliomas are induced
Carbon nanotubes (CNT)	Cell death/necrosis; cell membrane damage; respiratory functions are inhibited; damage to the mitochondrial DNA; inhibit bacterial clearance from lung tissues; induce granulomas and athereoschlerotic lesions
Zinc oxide nanoparticles (ZnO NP)	Proliferation of the cell
Iron oxide (Fe_3O_4)	Oxidative damage to the DNA
Copper zinc ferrite ($CuZnFe_2O_4$)/Copper oxide (CuO)	Oxidative damage to the DNA
Titanium dioxide (TiO_2)	Damage to DNA; inflammation in lungs; carcinogenesis; cell death; changes in metabolic activities
Silica nanoparticles (SiO_2)	Induces bronchoalveolar carcinoma-derived cells
Silver nanoparticle (Ag NP)	Affects the immune system including the liver, lungs, brain; causes cancerous growth; affects the reproductive organs, vascular system

heating and/or illumination equipment, as well as the integration of graphene and fullerenes to improve systems that store energy like batteries and condensers are further prospects (e.g., solar and wind) (Anikeeva et al. 2009; Ding et al. 2006; Flandrois and Simon 1999; Frackowiak and Beguin 2002).

It is crucial to realize their prospective movement and effects in air, soil, and water life as nanomaterials are devised and used. In order to detect and characterize nanoparticles that may be distributed from or integrated into building supplies, sophisticated analytical resources should be used. They need to measure the amount that could be toxic to the climate. There is also a need to emphasize environmentally friendly life cycle engineering of MNMs in building. Further research and investigation are a necessity to ensure that the workers working on the construction site are safe and that they are minimally exposed to nanoparticles. Work must be undertaken to ensure that the safe methods of design, manufacture, use, and removal and associated recycle, reuse, and remanufacturing programs are sufficient, which can increase the sustainability of both the construction industries and nanotechnology.

References

Abbasi E, Milani M, Fekri Aval S, Kouhi M, Akbarzadeh A, Tayefi Nasrabadi H, Nikasa P, Joo SW, Hanifehpour Y, Nejati-Koshki K, Samiei M (2016) Silver nanoparticles: synthesis methods, bio-applications and properties. Crit Rev Microbiol 42(2):173–180. https://doi.org/10.3109/1040841X.2015.1018131

Aderibigbe BA (2017) Metal-based nanoparticles for the treatment of infectious diseases. Molecules 22:E1370. https://doi.org/10.3390/molecules22081370

Ahamed M, AlSalhi MS, Siddiqui M, AlSalhi PM (2010) Silver nanoparticle applications and human health. Clin Chim Acta 411:1841–1848

AlMatar M, Makky EA, Var I, Koksal F (2017) The role of nanoparticles in the inhibition of multidrug-resistant bacteria and biofilms. Curr Drug Deliv 15:470–484. https://doi.org/10.2174/1567201815666171207163504

Ambika S et al (2015) Green biosynthesis of ZnO nanoparticles using *Vitex negundo* L. extract: spectroscopic investigation of interaction between ZnO nanoparticles and human serum albumin. J Photochem Photobiol B 149:143–148

Anikeeva PO, Halpert JE, Bawendi MG, Bulovic V (2009) Quantum dot light-emitting devices with electroluminescence tunable over the entire visible spectrum. Nano Lett 9:2532–2536

Arefi MR, Javeri MR, Mollaahmadi E (2011) To study the effect of adding Al_2O_3 nanoparticles on the mechanical properties and microstructure of cement mortar. Life Sci J 8:613–617

Bassegoda A, Ivanova K, Ramon E, Tzanov T (2018) Strategies to prevent the occurrence of resistance against antibiotics by using advanced materials. Appl Microbiol Biotechnol 102:2075–2089. https://doi.org/10.1007/s00253-018-8776-0

Bencana M, Moran JF, Iturbe-Ormaetxe I (1998) Independent oxygen free radical generation in plants subjected to environmental stress: toxicity and antioxidant protection. Plant Soil 201(1):137–147

Becher PF (1991) Microstructural design of toughened ceramics. J Am Ceram Soc 74:255–269

Blamey FPC, Edwards DG, Asher CJ (1983) Effects of aluminum, OH: Al and P: Al molar ratios, and ionic strength on soybean root elongation in solution culture. Soil Sci 136(4):197–207

Blecher K, Nasir A, Friedman A (2011) The growing role of nanotechnology in combating infectious disease. Virulence 2(5):395–401

Brown P, Kamat PV (2008) Quantum dot solar cells. Electrophoretic deposition of CdSe_C60 composite films and capture of photogenerated electrons with nC60 cluster shell. J Am Chem Soc 130:8890–8891

Buchanan CM, Gardner RM, Komarek RJ (1993) Aerobic biodegradation of cellulose acetate. J Appl Polym Sci 47:1709–1719

Castiglione MR, Giorgetti L, Geri C, Cremonini R (2011) The effects of nano-TiO_2 on seed germination, development and mitosis of root tip cells of *Vicia narbonensis* L. and *Zea mays* L. J Nanoparticle Res 13(6):2443–2449

Chaipanich A, Nochaiya T, Wongkaew, Tor Kittikul P (2010) Compressive strength and microstructure of carbon nanotubes-fly ash cement composites. Mater Sci Eng 527:1063–1067

Choi O, Deng KK, Kim N-J, Ross L Jr, Surampalli RY, Hu Z (2008) The inhibitory effects of silver nanoparticles, silver ions, and silver chloride colloids on microbial growth. Water Res 42(12):3066–3074

Crosera M, Bovenzi M, Maina G, Adami G, Zanette C, Florio C, Larese FF (2009) Nanoparticle dermal absorption and toxicity: a review of the literature. Int Arch Occup Environ Heal 82:1043–1055

Daniyal Md, Ameer A, Sabih A (2018) Application of nanomaterials in civil engineering. In: Khan ZH (ed) Nanomaterials and their applications. Advanced structured materials. Springer Nature, Singapore Pte Ltd. https://doi.org/10.1007/978-981-10-6214-8_6

De la Rosa G, Lopez-Moreno ML, de Haro D, Botez CE, Peralta-Videa JR, Gardea-Torresdey JL (2013) Effects of ZnO nanoparticles in alfalfa, tomato, and cucumber at the germination stage: root development and X-ray absorption spectroscopy studies. Pure Appl Chem 85(12):2161–2174. https://doi.org/10.1351/pac-con-12-09-05

Dehkordi EH, Mosavi M (2013) Effect of anatase nanoparticles (TiO2) on parsley seed germination (*Petroselinum crispum*) in vitro. Biol Trace Elem Res 155(2):283–286

Diao M, Yao M (2009) Use of zero-valent iron nanoparticles in inactivating microbes. Water Res 43(20):5243–5251

Ding Y, Alias H, Wen D, Williams RA (2006) Heat transfer of aqueous suspensions of carbon nanotubes (CNT Nanofluids). Int J Heat Mass Transf 49:240–250

Donaldson K, Seaton A (2012) A short history of the toxicology of inhaled particles. Part Fibre Toxicol 9:13

Donaldson K, Stone V, Gilmour PS, Brown DM, MacNee W, Malcolm AL, Derwent RG (2000) Ultrafine particles: mechanisms of lung injury. Philos Trans R Soc A Math Phys Eng Sci 358:2741–2749

Doyle ME, Glass KA (2010) Sodium reduction and its effect on food safety, food quality, and human health. Compr Rev Food Sci Food Saf 9(1):44–56

Drexler K (1981) Molecular engineering: an approach to the development of general capabilities for molecular manipulation. Proc Natl Acad Sci 78:5275–5278

Eichert T, Goldbach HE (2008) Equivalent pore radii of hydrophilic foliar uptake routes in stomata and leaf surfaces–further evidence for a stomatal pathway. Physiol Plant 132(4):491–502. https://doi.org/10.1111/j.1399-3054.2007.01023.x

Elliott KC (2011) Nanomaterials and the precautionary principle. Environ Health Perspect 119(6):A240–A245

Fageria NK, Baligar VC, Wright RJ (1990) Iron nutrition of plants: an overview on the chemistry and physiology of its deficiency and toxicity. Pesqui Agropec bras 25(4):553–570

Fang C, Yu X, Yu R, Liu P, Qiao X (2016) Preparation and properties of isocyanate and nanoparticles composite modified asphalt. Constr Build Mater 119:113–118

Feizi H, Kamali M, Jafari L, Rezvani Moghaddam P (2013) Phytotoxicity and stimulatory impacts of nanosized and bulk titanium dioxide on fennel (*Foeniculum vulgare* Mill). Chemosphere 91(4):506–511

Feizi H, Rezvani Moghaddam P, Shahtahmasebi N, Fotovat A (2012) Impact of bulk and nanosized titanium dioxide (TiO2) on wheat seed germination and seedling growth. Biol Trace Elem Res 146(1):101–106

Feynman RP (1960) There's plenty of room at the bottom: an invitation to enter a new field of physics. In: Proceedings of the annual meeting of the American Physical Society, California Institute of Technology, Pasadena, CA, USA, 29 Dec 1959. California Institute of Technology, Pasadena, CA, USA

Filon FL, Mauro M, Adami G, Bovenzi M, Crosera M (2015) Nanoparticles skin absorption: new aspects for a safety profile evaluation. Regul Toxicol Pharmacol 72:310–322

Fiskesjo G (1993) Allium test I: A 2–3 day plant test for toxicity assessment by measuring the mean root growth of onions (*Allium cepa* L.). Environ Toxicol Water Qual 8(4):461–470

Flandrois S, Simon B (1999) Carbon materials for lithium-ion rechargeable batteries. Carbon 37:165–180

Foy CD, Fleming AL (1982) Aluminium of two wheat genotypes related to nitrate reductase activity. J Plant Nutr 5(11):1313–1333. https://doi.org/10.1080/01904168209363064

Frackowiak E, Beguin F (2002) Electrochemical storage of energy in carbon nanotubes and nanostructured carbons. Carbon 40:1775–1787

Garcia JC, Simionato JI, Almeida VDC et al (2009) Evolutive follow-up of the photocatalytic degradation of real textile effluents in TiO2 and TiO2/H2O2 systems and their toxic effects on *Lactuca sativa* seedlings. J Braz Chem Soc 20(9):1589–1597

Ge Z, Gao Z (2008) Applications of nanotechnology and nanomaterials in construction. In: First international conference on construction in developing countries (ICCIDC–I). Advancing and integrating construction education. Research & Practice (Karachi, Pakistan 2008), pp 235–240

Geremias R, Fattorini D, F´avere VTD, Pedrosa RC (2010) Bioaccumulation and toxic effects of copper in common onion *Allium cepa* L. Chem Ecol 26(1):19–26

Giljohann DA et al (2010) Gold nanoparticles for biology and medicine. Angew Chem Int Ed Engl 49:3280–3294

Gillespie PA, Kang GS, Elder A, Gelein R, Chen L, Moreira AL, Koberstein J, Tchou-Wong K-M, Gordon T, Chen LC (2010) Pulmonary response after exposure to inhaled nickel hydroxide nanoparticles: short and long-term studies in mice. Nanotoxicology 4:106–119

Girishkumar G, Rettker M, Underhile M, Binz D, Vinodgopal K, McGinn P, Kamat P (2005) Single-wall carbon nanotube based proton exchange membrane assembly for hydrogen fuel cells. Langmuir 21:8487–8494

Goffredo GB, Citterio B, Biavasco F, Stazi F, Barcelli S, Munafò P (2017) Nanotechnology on wood: The effect of photocatalytic nanocoatings against *Aspergillus niger*. J Cult Heritage 27:125–136

Grande F, Tucci P (2016) Titanium Dioxide Nanoparticles: a risk for human health? Mini Rev Med Chem 16:762–769

Green MS, Etherington JR (1977) Oxidation of ferrous iron by rice (*Oryza sativa* L.) roots: a mechanism for waterlogging tolerance? J Exp Bot 28(3):678–690

Guerrini GL (2012) Photocatalytic performances in a city tunnel in Rome: NOx monitoring results. Constr Build Mater 27:165–175

Hajipour MJ, Fromm KM, Ashkarran AA et al (2012) Antibacterial properties of nanoparticles. Trends Biotechnol 30(10):499–511

Hartley W, Lepp NW (2008) Remediation of arsenic contaminated soils by iron-oxide application, evaluated in terms of plant productivity, arsenic and phytotoxic metal uptake. Sci Total Environ 390(1):35–44

Hauck TS, Ghazani AA, Chan WCW (2008) Assessing the effect of surface chemistry on gold nanorod uptake, toxicity, and gene expression in mammalian cells. Small 4(1):153–159

Hegazy M, Badawi A, El Rehim SA, Kamel W (2013) Influence of copper nanoparticles capped by cationic surfactant as modifier for steel anti-corrosion paints. Egypt J Pet 22:549–556

Hemeg HA (2017) Nanomaterials for alternative antibacterial therapy. Int J Nanomed 12:8211–8225. https://doi.org/10.2147/IJN.S132163

Hood E (2004) Nanotechnology: looking as we leap. Environ Health Perspect 112:A741–A749

Huang FM, Tai KW, Chou MY, Chang YC (2002) Cytotoxicity of resin-, zinc oxide-eugenol-, and calcium hydroxide based root canal sealers on human periodontal ligament cells and permanent V79 cells. Int Endod J 35(2):153–158

Huang X et al (2007) Gold nanoparticles: interesting optical properties and recent applications in cancer diagnostics and therapy. Nanomedicine (Lond) 2:681–693

Huh AJ, Kwon YJ (2011) Nanoantibiotics': a new paradigm for treating infectious diseases using nanomaterials in the antibiotics resistant era. J Control. Release 156(2):128–145

Hund-Rinke K, Simon M (2006) Ecotoxic effect of photocatalytic active nanoparticles (TiO_2) on algae and daphnids. Environ Sci Pollut Res 13(4):225–232

Hussain S, Sastry K (2014) Study of strength properties of concrete by using micro-silica and nano-silica. Int J Res Eng Technol 3:103–108

Ickrath P, Wagner M, Scherzad A, Gehrke T, Burghartz M, Hagen R, Radelo K, Kleinsasser N, Hackenberg S (2017) Time-dependent toxic and genotoxic effects of zinc oxide nanoparticles after long-term and repetitive exposure to human mesenchymal stem cells. Int J Environ Res Public Heal 14:1590

Irie H, Sunada K, Hashimoto K (2004) Recent developments in TiO2 photocatalysis: Novel applications to interior ecology materials and energy saving systems. Electrochem 72:807–812

Iv M et al (2015) Clinical applications of iron oxide nanoparticles for magnetic resonance imaging of brain tumors. Nanomedicine (Lond) 10:993–1018

Jasim B, Thomas R, Mathew J, Radhakrishnan EK (2017) Plant growth and diosgenin enhancement effect of silver nanoparticles in Fenugreek (*Trigonella foenum-graecum* L.). Saudi Pharm J 25(3):443–447. https://doi.org/10.1016/j.jsps.2016.09.012

Jin J, Chen B, Liu L, Liu R, Qian G, Wei H, Zheng J (2019) A study on modified bitumen with metal doped nano-TiO2 pillared montmorillonite. Materials 12:1910

John AR (1988) The iron and molybdenum use efficiencies of plant growth with different energy, carbon and nitrogen sources. New Phytol 109(3):279–287

Kandasamy S, Prema RS (2015) Methods of synthesis of nanoparticles and its applications. J Chem Pharm Res 7(3):278–285

Kang S, Herzberg M, Rodrigues DF, Elimelech M (2008a) Antibacterial effects of carbon nanotubes: size does matter. Langmuir 24:6409–6413

Kang S, Mauter MS, Elimelech M (2008b) Physicochemical determinants of multiwalled carbon nanotube bacterial cytotoxicity. Environ Sci Technol 42:7528–7534

Kang S, Pinault M, Pfefferle LD, Elimelech M (2007) Single walled carbon nanotubes exhibit strong antimicrobial activity. Langmuir 23:8670–8673

Karlsson HL, Cronholm P, Gustafsson J, Möller L (2008) Copper oxide nanoparticles are highly toxic: a comparison between metal oxide nanoparticles and carbon nanotubes. Chem Res Toxicol 21:1726–1732

Kataria S, Jain M, Rastogi A, Živčák M, Brestic M, Liu S, Tripathi DK (2019) Role of nanoparticles on photosynthesis: avenues and applications. Nanomaterials in plants, algae and microorganisms, pp 103–127

Kawashima S, Hou P, Corr DJ, Shah SP (2013) Modification of cement-based materials with nanoparticles. Cem Concr Compos 36:8–15

Khataee AR, Fathinia M, Naseri A et al (2014) Modeling and optimization of simultaneous photocatalysis of three dyes on ceramic-coated TiO2 nanoparticles using chemometrics methods: phyto toxicological assessment during degradation process. Res Chem Intermed 40(3):1283–1302

Khitab A (2012) Materials of construction (Allied Books, Pakistan) Edition: Ist Publisher. Allied Books, 75 Naqi Market, The Mall, Lahore, Pakistan

Khlebtsov N et al (2011) Biodistribution and toxicity of engineered gold nanoparticles: a review of in vitro and in vivo studies. Chem Soc Rev 40:1647–1671

Kollmeier M, Felle HH, Horst WJ (2000) Genotypic differences in aluminum resistance of maize are expressed in the distal part of the transition zone. Is reduced basipetal auxin flow involved in inhibition of root elongation by aluminum? Plant Physiol 122(3):945–956

Koren K et al (2015) Optical sensor nanoparticles in artificial sediments–a new tool to visualize O_2 dynamics around the rhizome and roots of sea grasses. Environ Sci Technol 49:2286–2292

Krishnaraj C, Ramachandran R, Mohan K, Kalaichelvan PT (2012) Optimization for rapid synthesis of silver nanoparticles and its effect on phytopathogenic fungi. Spectrochim Acta A Mol Biomol Spectrosc 93:95–99. https://doi.org/10.1016/j.saa.2012.03.002

Kumar A, Gupta A, Sharma KV, Nasir M (2013) Use of aluminum oxide nanoparticles in wood composites to enhance the heat transfer during hot-pressing. Eur J Wood Wood Prod 71(2):193–198

Kumar A, Vemula PK, Ajayan PM, John G (2008) Silver nanoparticle-embedded antimicrobial paints based on vegetable oil. Nat Mater 7:236–241

Kumar P, Morawska L (2014) Recycling concrete: an undiscovered source of ultrafine particles. Atmos Environ 90:51–58

Kurepa J, Paunesku T, Vogt S et al (2010) Uptake and distribution of ultrasmall anatase TiO2 alizarin red S nanoconjugates in *Arabidopsis thaliana.* Nano Lett 10(7):2296–2302

Laanbroek HJ (1990) Bacterial cycling of minerals that affect plant growth in waterlogged soils: a review. Aquat Bot 38(1):109–125

Larue C, Veronesi G, Flank A, Surble S, Herlin-Boime N, Carriere M (2012) Comparative uptake and impact of TiO2 nanoparticles in wheat and rapeseed. J Toxicol Environ Health A Curr Issues 75(13–15):722–734

Lee J, Mahendra S, Alvarez PJJ (2010) Nanomaterials in the construction industry: a review of their applications and environmental health and safety considerations. ACS Nano 4(7):3580–3590

Lellouche J, Friedman A, Lahmi R, Gedanken A, Banin E (2012) Antibiofilm surface functionalization of catheters by magnesium fluoride nanoparticles. Int J Nanomed 7:1175–1188

Lellouche J, Kahana E, Elias S, Gedanken A, Banin E (2009) Antibiofilm activity of nanosized magnesium fluoride. Biomaterials 30(30):5969–5978

Li GY (2004) Properties of high-volume fly ash concrete incorporating nano-SiO_2. Cem Concr Res 34:1043–1049

Lidén G (2011) The European commission tries to define nanomaterials. Ann Occup Hyg 55(1):1–5

Lin W, Huang YW, Zhou XD, Ma Y (2006) In vitro toxicity of silica nanoparticles in human lung cancer cells. Toxicol Appl Pharmacol 217:252–259

Ma H, Bertsch PM, Glenn TC, Kabengi NJ, Williams PL (2009) Toxicity of manufactured zinc oxide nanoparticles in the nematode *Caenorhabditis elegans*. Environ Toxicol Chem 28(6):1324–1330

Maine MA, Duarte MV, Suñé NL (2001) Cadmium uptake by floating macrophytes. Water Res 35(11):2629–2634

Małgorzata L (2014) Carbon nanotubes influence the compressive strength of cement composites. Tech Trans Civ Eng 1:5–11

Mann S (2006) Nanotechnology and construction. Nanoforum report 30

Mohajerani A, Tanriverdi Y, Nguyen BT, Wong KK, Dissanayake HN, Johnson L, Whitfield D, Thomson G, Alqattan E, Rezaei A (2017) Physico-mechanical properties of asphalt concrete incorporated with encapsulated cigarette butts. Constr Build Mater 153:69–80

Mohajerani A, Vajna J, Ellcock R (2018) Chromated copper arsenate timber: a review of products, leachate studies and recycling. J Clean Prod 179:292–307

Mohamed ASY (2015) Nano-innovation in construction. A new era of sustainability. In: Proceedings of the international conference on environment and civil engineering, Pattaya, Thailand, 24–25 Apr 2015, ICEACE, Pattaya, Thailand

Mohseni E, Ranjbar M, Tsavdaridis K (2015) Durability properties of high-performance concrete incorporating nano-TiO_2 and fly ash. Am J Eng Appl Sci 8:519–526

Momeni S et al (2015) A simple green synthesis of palladium nanoparticles with Sargassum algae and their electrocatalytic activities towards hydrogen peroxide. Appl Biochem Biotechnol 176:1937–1949

Mubaraki M, Ali SIA, Ismail A, Yuso NIM (2016) Rheological evaluation of asphalt cements modified with ASA polymer and Al2O3 nanoparticles. Procedia Eng 143:1276–1284

Nasrollahzadeh M et al (2015) Green synthesis of copper nano-particles using Ginkgo biloba L. leaf extract and their catalytic activity for the Huisgen [3+2] cycloaddition of azides and alkynes at room temperature. J Colloid Interface Sci 457:141–147

Nathan C, Cunningham-Bussel A (2013) Beyond oxidative stress: an immunologist's guide to reactive oxygen Pan species. Nat Rev Immunol 13(5):349–361

Nazari A, Riahi S (2011a) Optimization mechanical properties of Cr_2O_3 nanoparticles binary blended cementitious composite. J Compos Mater 45:943–948

Nazari A, Riahi S (2011b) The effects of Cr2O3 nanoparticles on strength assessments and water permeability of concrete in different curing media. Mater Sci Eng 528:1173–1182

Nazari A, Shadi R (2010) ZrO2 nanoparticles effects on split tensile strength of self compacting concrete. Mater Res 13:485–495

Nazari A, Rafiepour MH, Shadi R (2011) The effects of CuO nanoparticles on properties of self compacting concrete with GGBS as binder. Mater Res 14:307–316

Nazari A, Shadi R (2011) Effects of CuO nanoparticles on microstructure, physical, mechanical and thermal properties of self-compacting cementitious composites. J Mater Sci Technol 27:81–92

Nazari A, Shadi R, Sharin R, Shamekhi SF, Khademno A (2010a) Benefits of Fe_2O_3 nanoparticles in concrete mixing matrix. J Am Sci 6:102–106

Nazari A, Shadi R, Sharin R, Shamekhi SF, Khademno A (2010b) The effects of incorporation Fe2O3 nanoparticles on tensile and flexural strength of concrete. J Am Sci 6:90–93

Nazari A, Shadi R, Shirin R, Seyedeh FS, Khademno A (2010c) An investigation on the strength and workability of cement based concrete performance by using ZrO_2 nanoparticles. J Am Sci 6:29–33

Nejad FM, Azarhoosh A, Hamedi G, Azarhoosh M (2012) Influence of using nonmaterial to reduce the moisture susceptibility of hot mix asphalt. Constr Build Mater 31:384–388

Niroumand H, Zain M, Alhosseini SN (2013) The influence of nano-clays on compressive strength of earth bricks as sustainable materials. Procedia Soc Behav Sci 89:862–865

Nochaiya T, Chaipanich A (2011) Behavior of multi-walled carbon nanotubes on the porosity and microstructure of cement based materials. Appl Surf Sci 257:1941–1945

Oravisjärvi K, Pietikäinen M, Ruuskanen J, Niemi S, Laurén M, Voutilainen A, Keiski RL, Rautio A (2014) Diesel particle composition after exhaust after-treatment of an on-road diesel engine and modeling of deposition into the human lung. J Aerosol Sci 69:32–47

Pan X, Redding JE, Wiley PA, Wen L, McConnell JS, Zhang B (2010) Mutagenicity evaluation of metal oxide nanoparticles by the bacterial reverse mutation assay. Chemosphere 79(1):113–116

Park S, Lee YK, Jung M, Kim KH Chung N, Ahn EK, Lim Y, Lee KH (2007) Cellular toxicity of various inhalable metal nanoparticles on human alveolar epithelial cells. Inhalation Toxicol 19:59–65

Paz Y, Luo Z, Rabenberg L, Heller A (1995) Photooxidative self-cleaning transparent titanium-dioxide films on glass. J Mater Res 10:2842–2848

Pelgrift RY, Friedman AJ (2013) Nanotechnology as a therapeutic tool to combat microbial resistance. Adv Drug Deliv Rev 65(13–14):1803–1815

Peng HI et al (2011) Recent advancements in optical DNA biosensors: exploiting the plasmonic effects of metal nanoparticles. Analyst 136:436–447

Pereira L et al (2015) Metallic nanoparticles: microbial synthesis and unique properties for biotechnological applications, bioavailability and biotransformation. Crit Rev Biotechnol 35:114–128

Potera C (2010) Nanomaterials: transformation of silver nanoparticles in sewage sludge. Environ Health Perspect 118(12):A526–A527

Rahman MT, Hainin MR, Abu Bakar WAW (2017) Use of waste cooking oil, tire rubber powder and palm oil fuel ash in partial replacement of bitumen. Constr Build Mater 150:95–104

Rai M et al (2015) Strategic role of selected noble metal nanoparticles in medicine. Crit Rev Microbiol 1–24

Ramesh M, Palanisamy K, Babu NK (2014) Effects of bulk and nano-titanium dioxide and zinc oxide on physio morphological changes in *Triticum aestivum* Linn. Int J Glob Sci 3(2):415–422

Rana AK, Rana SB, Kumari A, Kiran V (2009) Significance of nanotechnology in construction engineering. Int J Recent Trends Eng 1:46–48

Rao PV et al (2015) Recent advances in nanotechnology-based diagnosis and treatments of diabetes. Curr Drug Metab 16:371–375

Reeves JF, Davies SJ, Dodd NJF, Jha AN (2008) Hydroxyl radicals are associated with titanium dioxide (TiO_2) nanoparticle-induced cytotoxicity and oxidative DNA damage in fish cells. Mutat Res 640:113–122

Rizzello L, Pompa PP (2014) Nanosilver-based antibacterial drugs and devices: mechanisms, methodological drawbacks, and guidelines. Chem Soc Rev 43(5):1501–1518

Royal Society (2004) Nanoscience and nanotechnologies: opportunities and uncertainties. The Royal Society, Science Policy Section, London, England

Ruot B, Plassais A, Olive F, Guillot L, Bonafous L (2009) TiO2-containing cement pastes and mortars: measurements of the photocatalytic efficiency using a rhodamine B-based colourimetric test. Sol Energy 83:1794–1801

Ruparelia JP, Chatterjee AK, Duttagupta SP, Mukherji S (2008) Strain specificity in antimicrobial activity of silver and copper nanoparticles. Acta Biomater 4(3):707–716

Saafi M, Romine P (2005) Nano and micro technology. Concr Int 27:28–34

Sarkar D, Pal M, Sarkar A (2014) Laboratory evaluation of asphalt concrete prepared with over burnt brick aggregate treated by zycosoil. Int J Civ Environ Struct Constr Archit Eng 8:1302–1306

Sato T, Diallo F (2010) Seeding effect of nano-CaCO3 on the hydration of tricalcium silicate. J Transp Res Board 2141:61–67

Schwab F, Zhai G, Kern M, Turner A, Schnoor JL, Wiesner MR (2016) Barriers, pathways and processes for uptake, translocation and accumulation of nanomaterials in plants. Nanotoxicology 10(3):257–278. https://doi.org/10.3109/17435390.2015.1048326

Selid PD et al (2009) Sensing mercury for biomedical and environmental monitoring. Sensors (Basel) 9:5446–5459

Serpone N, Pelizzetti E (1989) Photocatalysis: fundamentals and applications. Wiley, New York

Shaikh FUA, Supit SWM (2014) Mechanical and durability properties of high volume fly ash concrete containing calcium carbonate nanoparticles. Constr Build Mater 70:309–321

Singh P, Kim Y-J, Zhang D, Yang D-C (2016) Biological synthesis of nanoparticles from plants and microorganisms. Trends Biotechnol 34(7). http://dx.doi.org/10.1016/j.tibtech.2016.02.006

Smirnova E, Gusev A, Zaytseva O et al (2012) Uptake and accumulation of multiwalled carbon nanotubes change the morphometric and biochemical characteristics of Onobrychis arenaria seedlings. Front Chem Sci Eng 6(2):132–138

Sondi I, Salopek-Sondi B (2004) Silver nanoparticles as antimicrobial agents: a case study on *E. coli* as a model for Gram-negative bacteria. J Colloid Interface Sci 275(1):177–182

Song GB, Gu HC, Mo YL (2008) Smart aggregates: multifunctional sensors for concrete structures-a tutorial and a review. Smart Mater Struct 17:1–17

Stella WYW, Priscilla TYL, Djuriˇsi´c AB, Kenneth MYL (2010) Toxicities of nano zinc oxide to five marine organisms: influences of aggregate size and ion solubility. Anal Bioanal Chem 396(2):609–618

Stephan MK (2004) Iron oxide dissolution and solubility in the presence of siderophores. Aquat Sci 66(1):3–18

Stefanidou M, KazouA (2016) Testing the effectiveness of protective coatings on traditional bricks materials science. Constr Build Mater. Corpus ID: 138561739. https://doi.org/10.1016/J.CONBUILDMAT.2016.02.114

Tani FH, Barrington S (2005) Zinc and copper uptake by plants under two transpiration rates. Part I. Wheat (*Triticum aestivum* L.). Environ Pollut 138(3):538–547

Taniguchi N, Arakawa C, Kobayashi T (1974) On the basic concept of nano-technology. In: Proceedings of the international conference on production engineering, Tokyo, Japan, pp 26–29

Thakkar KN, Mhatre S, Parikh RY (2010) Nanomedicine: nanotechnology. Biol Med 6(2):257–262

Tiwari A, Chowdhury S (2012) An overview of application of nanotechnology in construction materials. Toxicity and assessment of potential occupational and environmental health risks. Crit Rev Toxicol 36:189–217

Vannini C, Domingo G, Onelli E, Prinsi B, Marsoni M, Espen L, Bracale M (2013) Morphological and proteomic responses of *Eruca sativa* exposed to silver nanoparticles or silver nitrate. PLoS ONE 8(7):68752. https://doi.org/10.1371/journal.pone.0068752

Wang S, Lawson R, Ray PC, Yu H (2011) Toxic effects of gold nanoparticles on *Salmonella typhimurium* bacteria. Toxicol Ind Health 27(6):547–554

Wiemann M, Vennemann A, Blaske F, Sperling M, Karst U (2017) Silver nanoparticles in the lung: toxic effects and focal accumulation of silver in remote organs. Nanomaterials 7:441

Yamamoto Y, Kobayashi Y, Matsumoto H (2001) Lipid peroxidation is an early symptom triggered by aluminum, but not the primary cause of elongation inhibition in Pea roots. Plant Physiol 125(1):199–208

Yang K, Ma Y (2010) Computer simulation of the translocation of nanoparticles with different shapes across a lipid bilayer. Nat Nanotechnol 5(8):579–583

Yazdi NA, Arefi MR, Molla Ahmadi E, Nejand BA (2011) To study the effect of adding Fe2O3 nanoparticles on the morphology properties and microstructure of cement mortar. Life Sci J 8:550–554

Ye Q, Zhang ZN, Kong DY, Chen RS (2007) Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume. Constr Build Mater 21:539–545

Zafar H, Ali A, Ali JS, Haq IU, Zia M (2016) Effect of ZnO nanoparticles on *Brassica nigra* seedlings and stem explains growth dynamics and antioxidative response. Front Plant Sci 7:535. https://doi.org/10.3389/fpls.2016.00535

Zahir AA et al (2015) Green synthesis of silver and titanium dioxide nanoparticles using Euphorbia prostrata extract shows shift from apoptosis to G_0/G_1 arrest followed by necrotic cell death in *Leishmania donovani*. Antimicrob Agents Chemother 59:4782–4799

Zhang MH, Li H (2011) Pore structure and chloride permeability of concrete containing nanoparticles for pavement. Constr Build Mater 25:608–616

Zhang W, Suhr J, Koratkar N (2006) Carbon nanotube/polycarbonate composites as multifunctional strain sensors. J Nanosci Nanotechnol 6:960–964

Zhenhua L, Huafeng W, Shan H, Yang L, Miao W (2006) Investigations on the preparation and mechanical properties of the nano-alumina reinforced cement composite. Mater Lett 60:356–359

Zhu W, Bartos PJM, Porro A (2004) Application of nanotechnology in construction: a summary of a state-of-the-art report. Mater Struct 37:649–658