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# Toward green revolution in concrete industry: The role of nanotechnology (A review)

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**Abstract:** Nowadays, the development of nanotechnology is faster than before due to its interdisciplinary nature. Other branches of engineering have started employing this technology in the process of their development; one example would be concrete science and technology. Nearly a decade has passed since the first application of nano-particles in a matrix of concrete products. During this time period, two directions have formed in the process of researchers' investigations. The first route is the precise monitoring of the microstructure and macrostructure of concrete products with the help of nanotechnology tools and methods. The second route is the development of concrete products with nanotechnology; however, a more detailed review is needed to backup this development. In today's world, any development must be sustainable; therefore, ecologically sustainable development can either assist the development of a technology or the society. This paper reviews the role of nanotechnology in relation to the development of green technology with respect to recent developments in nano-concrete technology. Finally, a functional model has assisted the rise of green concrete technology with the aid of nanotechnology.

**Key words:** Green technology, nanotechnology, nano material, concrete, concrete technology

## INTRODUCTION

Today, concrete is the most useful material in the world after water. This popularity is due to numerous functionalities of concrete structures. Managing the costs of constructing concrete structures, creating fast and convenient architectural concepts, and supervising the cost efficiency of concrete production are just a few aspects involved in developing more concrete structures. Due to its popularity, about 10 billion tons of concrete in the world are produced and consumed each year (Meyer, 2009). From a different perspective, one can see that the concrete industry has a significant impact on the environment. In order to consider the sustainable development criteria, we must divide them into three categories: economic, social, and environmental impacts. Therefore, in order to estimate the effects of concrete products development and application of control strategies for this development, one must study the concrete life cycle.

The characteristics of sustainable development include ecological sustainable development and its impacts on the environment. Thus, this would mean that the development of a product should not lead to the destruction of the environment or the extinction of an organism. With the same vision, the development of concrete products is recognized as an environmental destructive phenomenon associated with environmental pollution.

The environmental impacts of manufacturing and developing cement-based materials are illustrated in Fig. 1. As can been seen, concrete production is the result of mixing several raw materials. Each of these raw materials is extracted from nature. On the other hand, the production process, transportation, and concrete casting are associated with energy consumption and pollution. For example, fuel consumption in cars, trucks, truck mixers, and bunkers leads to exhausting pollution such as air pollution. Moreover, the production of concrete from raw materials requires energy consumption during production which also leads to pollution. Also, the compaction of concrete during construction is associated with noise pollution.

More precise investigations show that energy consumption leads to pollution because of the extracting and burning the fuel. In some aspects, the cement industry is clarified as a significant pollutant because it produces around 5% of global manmade carbon dioxide ($CO_2$) emissions (Damtoft, Lukasik, Herfort, Sorrentino, & Gartner, 2008). Last but not least, the destruction of concrete structures creates large volumes of concrete debris. Thus, if the concrete industry tends to move toward sustainable development, the environmental impacts of concrete products should be reduced along with improving their characteristics in order to reach larger markets and economical advancement.

It has been nearly a decade that the concrete industry has applied nanotechnology. The entrance of nanotechnology in the concrete industry occurred by employing one of the most important nano-products (nano-materials) in cement-based products. Preliminary results obtained from proper operation of nano-particles in the

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structure of cement-based materials indicated improved mechanical performance and durability (Ji, 2005; H. Li, Xiao, & Ou, 2004a, 2004b). Before this, the nanotechnology was applied as a microstructural device to examine the matrix of cement-based materials in the concrete industry. Accordingly, the development of nanotechnology in the concrete industry splits into two directions: the introduction of nano-materials (such as nano-particles, chemicals based on nanotechnology and nano-fibers), and the introduction of nano devices and computational nano-modeling software such as the Scanning Electron Microscopy, Atomic Force Microscopy, Nuclear Magnetic Resonance, X-Ray Diffraction, X-Ray Fluorescence, Fourier Transform Infra-Red, BET, Nano-sensors, Molecular Dynamics (MD), ab initio and etc.

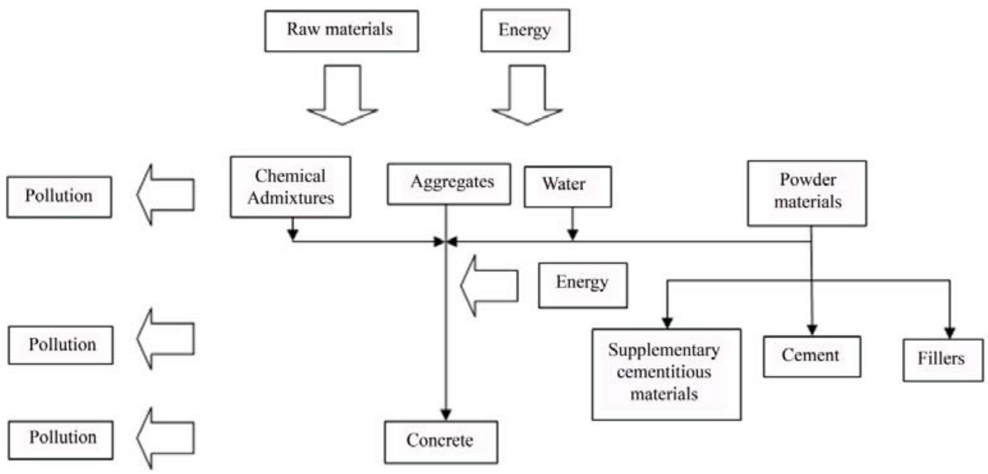


**Fig. 1:** Resource consumption flow and emissions in concrete industry.

As a result, the purpose of this paper is to present a new vision about the effectiveness of nanotechnology in reducing the environmental impacts of concrete industry and concrete products. Therefore, this effectiveness and its various proposed aspects will be reviewed precisely. Finally, a model will be presented for making green concrete industry with the use of nanotechnology. Of course, new approaches involving nano-materials have unknown safety risks. Therefore, in this paper, by supposing that the risks caused by nano-particles have been controlled (which are mostly related to health risk), only direct effects of nanotechnology in the development of green concrete technology will be demonstrated.

### *2. Green Concrete Technology:*

Based on before-mentioned discussions, the concrete industry (with regard to the cement industry as its subset) has destructive effects on the environment. These effects are classified in three categories. The first category is the consumption of non-renewable and renewable resources; the next category includes environmental pollution, and the last category is the creation of waste during production, transmission, consumption, and finally the demolition of cement-based products at the end of their lifetime. Of course, it should be noted that the most important gas created in this industry is $CO_2$, which is emitted from cement production. However, we can even assume cement production does not create other greenhouse gases (Damtoft, *et al*., 2008). But, by considering the life cycle of concrete products, one shouldn't neglect the production of other greenhouse gases caused by burning fuels in cement and concrete production, and transportation. Therefore, strategies to create clean concrete industry should be implemented in order to reduce consumption of natural resources (raw materials and energy) and control residue and pollution. Accordingly, the study furthers the discussion of the green concrete industry. Fig. 1 illustrated that various raw materials are consumed to produce powder materials, aggregates, and also liquids used in concrete production. The energy is employed for each component of concrete production, transportation and mixing of components. Therefore, the energy is used to produce concrete. On the other hand, all levels of extraction, production of concrete components and concrete production, bring about some pollution.

Almost 55 to 75 percent of concrete volume is aggregate and 25 to 45 percent is paste (including powder, water, and chemical additives). Thus, one must provide an appropriate model with realistic views in order to reduce consumption sources such as aggregate consumption (coarse and fine), powder materials, and water. The amount of chemical additives is negligible when compared to the other concrete components. The required water for concrete should be replaced with disposable water which is wasted in many countries all over the world. Some examples would be wastewater, collected rainwater in the cities, or disposed water from concrete factories. Of course, regarding the standards and limitations for water quality applied in concrete, water purification for these alternative water types seems obligatory.

According to the amounts used for each of the ingredients of concrete, the optimum use of aggregates and powder materials makes an enormous impact on reducing the consumption of natural resources in the concrete industry. Many worldwide studies have been conducted on the basis of the above-mentioned subjects. Therefore, this study tries to express solutions offered in contemporary researches in order to reduce the consumption of the two major components of concrete (aggregate and cementitous materials).

However, regarding the importance of water resource maintenance and management in the present century and especially in countries with hot and dry climate, by the aid of nano-technology, water procuring methods needed for concrete constructions have been investigated and developed which will be concisely mentioned in the following.

According to recent studies (Hansen & Hedegard, 1984; Rahal, 2007), using residues from the destruction of concrete structures completes the life cycle of concrete. This completion occurs because the residues can be used as concrete aggregate after the crushing process and gradation. Also, application of used industrial residues as the aggregates for concrete is confirmed. These industrial residues have the load bearing ability like residue of waste bricks, waste tire rubber, Slag, and Glass (Alhumoud, Al-Mutairi, & Terro, 2008; Cachim, 2009; Khaloo, Dehestani, & Rahmatabadi, 2008; Manso, Polanco, Losanez, & Gonzalez, 2006).

On the other hand, using waste powder materials disposed by other industries as pozzolanic materials for cement replacement made an acceptable reduction on the demand of cement (Ahmad, Omar, Malek, Noor, & Thiruselvam, 2008; Cyr, Coutand, & Clastres, 2007; Lam, Wong, & Poon, 1998; Saraswathy & Song, 2007). Fly ash, silica fume, rice husk ash, sewage sludge ash, palm oil fuel ash, and other types of ash could be cited as waste pozzolanic ashes (Ahmad, *et al*., 2008; Cyr, *et al*., 2007; Lam, *et al*., 1998; Saraswathy & Song, 2007). Moreover, some residues of different industries called filler powders are currently used in the concrete products (Topcu, Bilir, & Uygunoglu, 2009).

Today, high volume consumption of waste pozzolanic materials and fillers is desired by researchers (Felekoglu, 2007; Meyer, 2009; Poon, Lam, & Wong, 2000). Through this strategy, further cement reduction can be achieved. Accordingly, tangible progress could be gained in green-concrete industry if the strength and durability characteristics of green concrete materials are improved. As a result, green-concrete would be directly utilized in construction as structural concrete.

On one hand, using other strategies to reduce energy consumption and raw materials during cement production has also been considered. Optimizing the energy consumption during cement production process, application of waste powder materials to produce waste powder blended cements, belite cements production to reduce energy consumption and also decrease in $CO_2$ emission, fuels obtained from waste materials and recycled residue from cement factory for the production of concrete and cement (Damtoft, *et al*., 2008; Dong & Lee, 2009; Karbassi, Jafari, Yavari, Hoveidi, & Kalal, 2010; Siddique, 2006) are some of these strategies.

Another important point that must be considered in the life cycle of concrete is the production of high volume residue after destroying huge concrete structures. This case is observed more frequently in developing countries since the concrete structures have shorter lifetime. As a result, whenever the quality of applied cement-based materials is lower, the serviceability of structures is lower, and it will therefore be destroyed in a shorter period of time. On the other hand, new structures which are replaced with previous ones are required additional cementitious materials to fabricate concrete elements. This would give another warning regarding the use of new concrete materials. Accordingly, the lesser the quality of concrete materials used in construction, the lower the period of waste production; therefore, the use of concrete materials, in a specified time interval, increases. Thus, using high quality concrete materials is essential in terms of environmental and economic criteria. In addition, in the past two decades, new concrete materials have been supplied and offered to the construction market, improving flow-ability, mechanical characteristics, and durability. Self-Compacting Concretes, Ultra High Performance Concretes, and Reactive Powder Concretes are examples of these new products. Applying these types of concrete in conventional and special structures has increased the lifetime and serviceability of these structures. If these types of concretes are made from waste materials, it will increase the performance and contribute several positive environmental impacts. As a result, the development of the recycling division in the concrete industry is the most important strategy to achieve green concrete industry.

Moreover, it should be noted that some of the cement-based materials, such as repair grouts and mortars, are used for retrofitting and repairing concrete structures. Retrofitting and rehabilitating are required when any structure does not have proper operation under various factors. These materials are usually applied when the destruction is visible (such as cracks in structural members formed at the time of loading). Therefore, if the behaviour and performance of structures is monitored, preventative measures could be taken to stop or control the destructive process. Improvements during the retrofitting and repairing process also lead to reduced consumption of cement-based repairing materials. In addition, here, more discussion should be done about necessity of compatibility of concrete and general cement-based materials with environment. This topic can be discussed from different aspects. Firstly, the production of primary materials needed for production of cement-based materials, and also constructing concrete products significantly aggravate the environmental damages. As mentioned before, obtaining energy and raw materials resources, emission of greenhouse gasses during the production process of each one of the constituents and also final product, and their transportation are some remarkable negative effects in the process of producing cement-based materials. However the second aspect of concrete products environmental impact is their effects after the production phase, during service life, and after demolition. Carbonation and leaching of cement-based materials are two of the most important examples of such influences. When concrete is exposed to Carbon Dioxide ($CO_2$) existing in the environment, it will be damaged by infiltration of this gas into the matrix and its reaction between $Ca^{2+}$ located in the pore solution of cement-based materials, and consequent formation of Calcium Carbonate ($CaCO_3$). The crucial point in here is pH loss in the pore solution which results in dissolving and leaching of principal production of hydration reaction (calcium-silicate-hydrate).

Alongside, it can be deduced that carbonation, which is a natural phenomenon, have damaging effects (like reduction of strength and durability) on concrete structures (Bertos, Simons, Hills, & Carey, 2004; Roy, Poh, & Northwood, 1999). The reason for carbonation is referred to different factors, but if we improve the strength of cement-based matrix and partly reduce its pores, we will be able to decrease the carbonation intensity. Another issue is leaching of cement-based materials in the presence of fluids. This problem is aggravated if water possesses acidic property, or in the other words, less pH value compared to pore solution (Alonso, Castellote, Lorente, & Andrade, 2006; Rougelot, Burlion, Bernard, & Skoczylas, 2010). This property contributes to hydrolysis of cement paste hydrates, increase in pores, and strength loss (Agostini, Lafhaj, F.Skoczylas, & Loodsveldt, 2007; Alonso, *et al*., 2006; D. Bentz & E.Garboczi, 1992; Carde & Francois, 1999; Carde, Francois, & JM.Torrenti, 1996; Rougelot, *et al*., 2010). This issue matters more while the concrete structure is made for some specific usage (e.g. nuclear waste storage) or the structure (or its foundations) is surrounded by ground water (Alonso, *et al*., 2006).

On the other hand, when we dispose the construction debris in inappropriate landfills, they may gradually deteriorate the surrounding ground water by subsequent leaching of concrete debris and dissolving of concrete matrix ions into the water. Because the most important leaching ion is $Ca^{2+}$, the ground water will possess hardness. Water hardness can negatively affect the water quality and its usages for mankind. Concisely, concrete structures will be damaged and ground water will be deteriorated. Therefore, if we improve the matrix of cement-based materials, we will be able to considerably aid their environmental compatibility. In this way, we can oppose one of the most important factors of cement-based materials environmental compatibility known as leaching of heavy metals and salts(Hohberg, Groot, Veen, & Wassing, 2000).

### *3. Nanotechnology And Green Revolution In Concrete Industry:*

The strategies proposed in the previous section clarify that the development of concrete products and the use of waste materials for concrete production are major factors in achieving green construction and concrete products. Moreover, it can be seen that nanotechnology is a more appropriate tool for the development of green concrete industry. Nano-technology can also serve by creating new nano-technology-based products which reduces environmental pollution produced by other industries. This part of the paper performs a detailed and comprehensive study on former worldwide research done regarding nanotechnology in the development of cement-based products. This issue could be called the “green revolution” in the concrete industry. Also, more practical strategies for developing green products in the concrete industry have been expressed.

Based on research and studies presented in the second part of the current paper, the efficacy of nano-particles in the development of green concrete can be summarized in the following:

- Reducing consumption of resources;
- Reducing environmental pollution;
- Monitoring performance of concrete products.

The involvement of nanotechnology in green concrete industry is illustrated in Fig. 2. Based on this study, the triple effectiveness of nanotechnology, in order to make the concrete industry greener, is observed.

### *3.1. Reduction of Natural Resources Consumption:*

The development of concrete products as depicted in Fig. 3, is formed as a result of increasing the rheological properties, strength, and durability of concrete products. Thus, this increases the lifetime of the product. As mentioned in the second part of this paper, this issue also reduces consumption of natural resources and, in turn, postpones the need of creating new structures or using materials for repairs and retrofitting. On the other hand, the development of green products and new concrete products may lead to better performance and longer service life of concrete structures. Developing the properties of concrete products fabricated with concrete residue (e.g. aggregates and fillers) and the residue of other industries (as aggregate, filler and pozzolanic materials) increases the demand for these products due to the strength and durability (which satisfies limitation of codes). As a result, the consumption of more waste residue prevents the reduction of natural resources. Additionally, nano-filtration can be applied for the purification of waste water such as rainwater, sewage, and even water from washing stand mixers and truck mixers. This issue is important for countries that are facing water shortages. Considering the trend of rising global temperatures (global warming) and loss of tap water, one must think about optimizing water consumption.

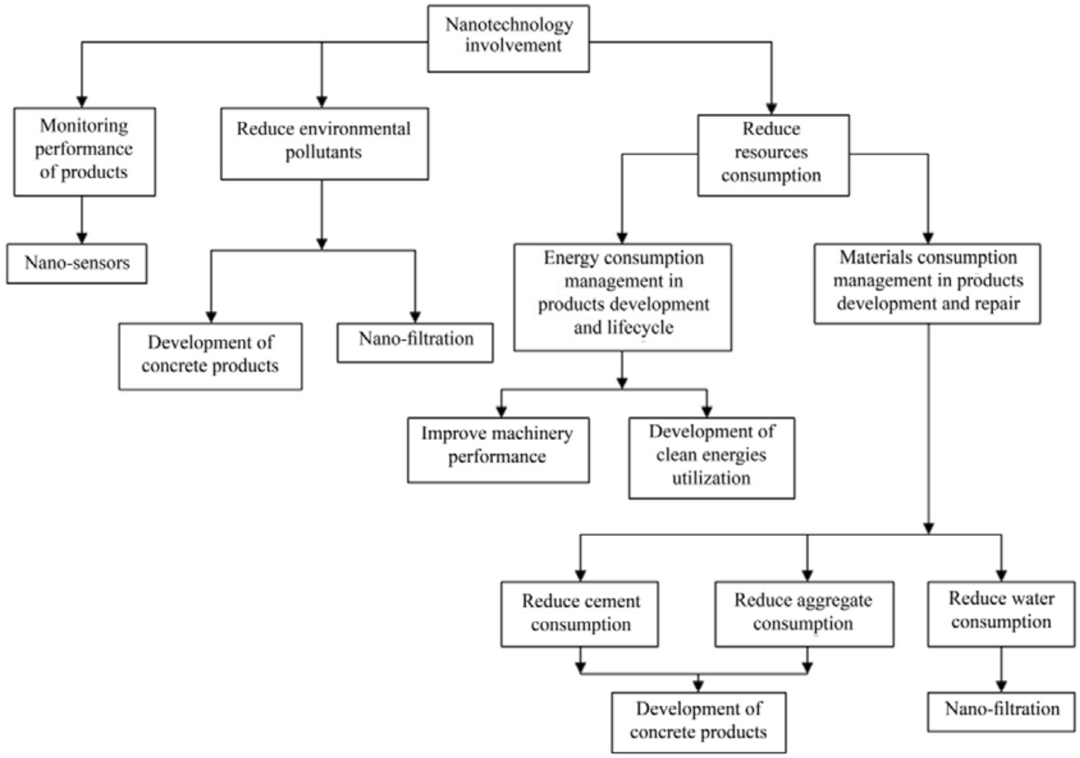


**Fig. 2:** The involvement of nanotechnology in concrete industry.

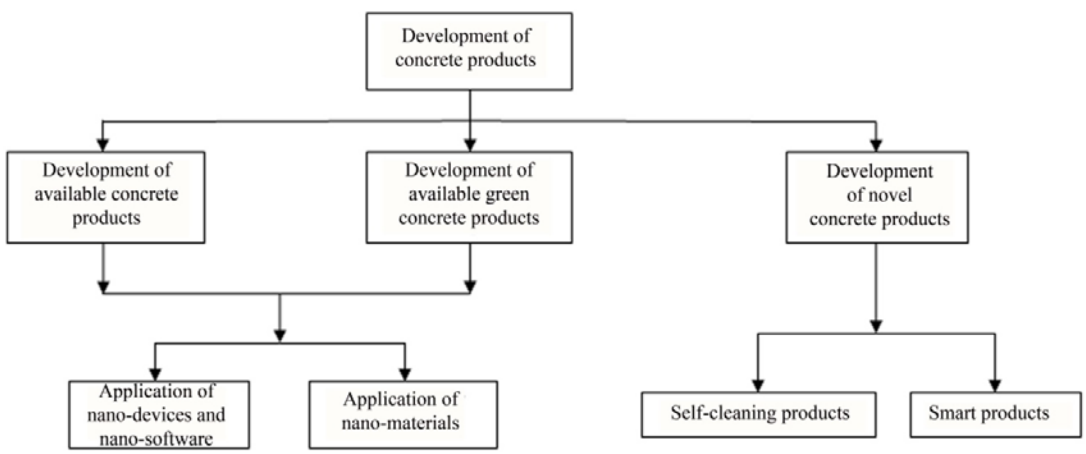


**Fig. 3:** Development trend of concrete products by nanotechnology.

According to Fig. 3, the development of concrete products accompanied by nanotechnology is presented in three categories:

1- Development of available concrete products;
2- Development of available green concrete products;
3- Development of novel concrete products.

Before explaining each of the above factors, a short discussion would be necessary about nano-materials as the most important type of nanotechnology products used to produce concrete elements. As expressed before, using nano-materials in the cementitious matrix became popular nearly a decade ago. Nano-materials (materials that have been produced by nanotechnology with nanometres dimensions) used in the cementitious materials matrix are categorized in 3 groups: powder and colloidal nano-particles, nano chemical admixtures, and nano-fibers. Nano-particles are produced using both top-down and bottom-up methods. Decreasing the particle size and increasing the surface area increases the intensity of the reaction. This issue increases the performance of pozzolanic materials. On the other hand, it improves the filling-ability of pozzolanic materials and fillers. These property improvements develop concrete features: including concrete rheology, concrete strength, and durability (Binici, Aksogan, Cagatay, Tokyay, & Emsen, 2007; Chindaprasirt, Jaturapitakkul, & Sinsiri, 2007; Habeeb & Fayyadh, 2009). Thus, using nano-tools such as planetary ball mill or high energy ball mill can reduce particle size and dimensions toward nano-scale sizes (Koch, 1993). This issue will sharply increase the particles reactivity and micro-filling effects. Nano-materials production can also be achieved by the bottom-up approach and chemical reactions. In these methods, the favourite arrangement and characteristics of atoms can be achieved and desired changes can be conducted on nano-materials. However, in recent years, the nano-dimensions have become achievable by both methods. As a result, it would be an introduction to a new method based on the two before-mentioned methods (Whatmore, 2001).

Most of the nano-particles used in the concrete industry have been produced by bottom-up methods. Nano-particles production is considered from three aspects. The first aspect is the production of nano-materials from the residue made by other industries. The second aspect is the production of nano-particles with the strongest reactivity with cement particles which has to be a super-pozzolan. On the other hand, a combination of these two aspects can be the ultimate goal. Furthermore, researchers have been able to achieve the nanoparticle zinc-iron oxide ($ZnFe_2O_4$) from electric arc furnace dust (Flores-Velez & Dominguez, 2002) which improved the strength and durability of concrete specimens. Furthermore, other researchers applied rice husk ash to synthesize silica nano-particles (Amutha, Ravibaskar, & Sivakumar, 2010; Thuadaij & Nuntiya, 2008). It should be noted that the before-mentioned issue is along with the movement toward ultimate goal which means developing green products by green strategies. This is because silica nano-particles, a type of nano-particle produced from waste products, have been known as the best nano-particles applied in the structure of cement-based materials. This issue is discussed further within the paper.

Other types of nano-particles or nano-sized materials produced by the bottom-up methods and applied in the cement-based materials matrix include: silica nano-particles (nano-$SiO_2$) (Givi, Rashid, Aziz, & Salleh, 2010, 2011; Khaloo, Hosseini, Booshehrian, & Madari, 2007; Senff, Labrincha, Ferreira, Hotza, & Repette, 2009) , nano-iron oxide (nano-$Fe_2O_3$) (H. Li, *et al*., 2004a, 2004b), nano-alumina (nano-$Al_2O_3$) (Z. Li, Wang, He, Lu, & Wang, 2006), nano-clay (Chang, Shih, Yang, & Hsiao, 2007; Morsy, SH, & Aqel, 2010; Tregger, Pakula, & Shah, 2010), nano titanium oxide (nano-$TiO_2$) (H, Zhang, & Ou, 2007; Jayapalan, Lee, Fredrich, & Kurtis, 2010; Jayapalan, Lee, & Kurtis, 2009; H. Li, Zhang, & Ou, 2006), nano-calcium carbonate (nano $CaCO_3$) (Sato & Beaudoin, 2006, 2007; Sato & Diallo, 2010), and nano-cement (Dham, *et al*., 2010; Luna & Bernal, 2005). A nano-particle in the structure of the cement-based materials is not used only in terms of nano-particle reaction. Other considerations should be studied to make a decision considering performance, lower prices, and better accessibility. Accordingly, the silica nano-particles, whether in terms of performance or of price and accessibility, are the most appropriate nano-particles used in the concrete industry (Hosseini & Booshehrian, 2011). Nano-particles are used to improve the mechanical properties and durability of cement-based products according to their different behaviours (Chang, *et al*., 2007; Dham, *et al*., 2010; Givi, *et al*., 2010, 2011; H, *et al*., 2007; Hosseini & Booshehrian, 2011; Jayapalan, *et al*., 2010; Jayapalan, *et al*., 2009; Khaloo, *et al*., 2007; H. Li, *et al*., 2006; Z. Li, *et al*., 2006; Luna & Bernal, 2005; Morsy, SH, *et al*., 2010; Peters, Rushing, Landis, & Cummins, 2010; Sato & Beaudoin, 2006, 2007; Sato & Diallo, 2010; Senff, *et al*., 2009; Tregger, *et al*., 2010). Nano-particles improve the performance of cement-based materials matrix according to possession of one or more of the following categories (Hosseini, Booshehrian, & Farshchi, 2010).

- To increase the production of calcium - silicate - hydrate (CSH) gel due to pozzolanic reaction and reduce amounts of $Ca(OH)_2$ crystals;
- To prevent the excessive growth of crystals in the matrix and control crystallization;
- Micro and nano-filling;
- Development of hydration reaction.

The second type of nano-materials applied in the structure of cement-based materials is nano-chemical additive. These materials improve the rheological performance of concrete products and contribute major support in order to produce specific concretes such as SCC, UHPC and RPC. Nano viscosity modifying agents (DP. Bentz, Snyder, & Peltz, 2010; Diamantonis, *et al*., 2010; Leemann & Winnefeld, 2007), nano super plasticizers (Raki, Beaudoin, & Mitchell, 2004), and nano-polymers are some examples of these materials (BW. Jo, Park, & Kim, 2008). Finally, the third group of nano-materials is nano-fibers used in the matrix of concrete materials. According to the types of fibers in the structure of cement-based materials, carbon nano-fibers (CNF) (Metaxa, Konsta-Gdoutos, & Shah, 2010; Sanchez & Ince, 2009; Sanchez, Zhang, & Ince, 2009), carbon nanotubes (CNT) (Cwirzen, *et al*., 2009; Konsta-Gdoutos, Metaxa, & Shah, 2010; Gy. Li, Wang, & Zhao, 2005;

Makar & Chan, 2009; Manzur & Yazdani, 2010; Musso, Tulliani, & Ferro, 2009; Yu & Kwon, 2009) and nano-cellulose fibers can be indicated (Peters, *et al*., 2010). Nano-fibers improve the mechanical characteristics, create higher impact capacity, and reduce cracks in concrete specimens. These materials increase tensile and bending strengths by creating a bridge between micro cracks in the matrix of cement-based materials and also acting as nucleating sites for the hydration products (Cwirzen, *et al*., 2009; Konsta-Gdoutos, *et al*., 2010; Gy. Li, *et al*., 2005; Makar & Chan, 2009; Manzur & Yazdani, 2010; Metaxa, *et al*., 2010; Musso, *et al*., 2009; Peters, *et al*., 2010; Sanchez & Ince, 2009; Sanchez, *et al*., 2009; Yu & Kwon, 2009).

However, if these nano-particles are not being dispersed appropriately and agglomerate in the matrix of cement-based materials, their performance in the matrix will be reduced. As a result, high range water reducer supperplasticizers should assist nano-particles, and also usage of low dosage nano-particle contents (less than 5%) would aid the fabrication process (Hosseini, *et al*., 2010; Senff, Hotza, Repette, Ferreira, & Labrincha, 2010). Moreover, using lower amounts of these types of materials are preferred due to reducing the costs. The other notable point is the increase in shrinkage while the nano-particles are added (Senff, *et al*., 2010). This issue can be effective in serviceability of the structure. Low dosage application of nano-particles can prevent this defect in an acceptable manner; however, mostly we have to utilize the shrinkage reducing agents.

At the end, we should mention the application of nano-materials hybrid system as one system having positive strategic behaviour which can be a noteworthy issue for future studies. Alongside, in the most recent research conducted on this area, application of nano-fibers (CNT) along with nano-clay has been investigated (Morsy, Alsayed, & Aqel, 2010).

The results have revealed an optimum proportion for hybrid system of CNT-nano-clay (6% nano-caly with 0.02% CNT) which demonstrates that the hybrid system can perform differently compared to separate usage of each nano-material. Therefore, in near future, we would be able to produce cement-based nano-composites with singular behaviour by the aid of multi-system cementitious blends of different nano materials. Hence, these hybrid systems can extremely develop the performance of different types of cement-based materials.

A remarkable point which should be considered here is the development of computational materials science. By the aid of different computational methods (such as “ab initio” and “molecular dynamics”), researchers have been investigated the microstructure of cement-based composites (Churakov, 2008; Kalinichev, Wang, & Kirkpatrick, 2007; Liu & Shi, 2010; Murray, Subramani, Selvam, & Hall, 2010; Pellenq, Lequeux, & Damme, 2008). As an outcome, with a comprehensive knowledge about cement-based composites, one can improve their properties and achieve significant results with minute changes. Therefore, in all the following sections, while discussing about the development of cement-based materials, it should be considered that we can enhance the performance of these materials by developing the atomic scale modelling methods and chemical and physical microstructural investigation. Accordingly, utilizing the microstructural modelling (in molecular and atomic scales) is permanently known as one alternative in developing the microstructural and macrostructural properties of cement-based composites.

#### *3.1.1. Development Of Available Concrete Products:*

Considering the before-mentioned subjects, nano-materials increase the lifetime of cement-based products by improving rheological properties, strength, and durability. On the other hand, these materials help the formation of new concrete products such as SCC, UHPC, HPC, RPC, etc. (Baomin, Lijiu, & Lai, 2008; Dham, *et al*., 2010; Diamantonis, *et al*., 2010; BBW. Jo, Kim, & Lim, 2007; Wille & Loh, 2010).

On one side, strength enhancement of RPC containing nano-$SiO_2$ compared to concretes made by silica fume particles, and on the other side, the development of interfacial transition zone (BBW. Jo, *et al*., 2007) are witnesses for extraordinary performance of particles with nano-scale dimension respect to micro-scale ones. Also, freezing resistance of HPC by the aid of nano-particles has been reported (Baomin, *et al*., 2008). The principal reason for this event is micro-structural development of concrete reinforced with nano-$SiO_2$ particles (Baomin, *et al*., 2008).

In another research, by applying different types of nanocement, the behavior of these nano-particles in the matrix of RPC has been investigated (Dham, *et al*., 2010). Development of compressive and splitting tensile strength was confirmed by the experimental results. The important point is that the elastic modulus remained nearly constant which contributes to increase in fracture energy of RPC; this happens due to enhancement of tensile strength in an almost constant modulus of elasticity which would be extremely considerable for RPC regarding its brittle nature (one of the most important disadvantages of RPC). Accordingly, we can develop the optimized cementitious systems by the application of nanocement particles and other nano-materials. Besides nano-particles, nano-fibers associate the fabrication of special concretes as well (Wille & Loh, 2010); because, by using low concentrations of multi walled carbon nano-tubes, the bond behavior of steel fibers pulled out of UHPC significantly increased. Also, if we uniformly distribute these nano-fibers in the matrix of cement-based composites, we will be able to appropriately improve the compressive and bending strength of specimens (Wille & Loh, 2010).

These applications improve the lifetime and performance of concrete structures. Therefore, the supply and demand of alternative structures during specific periods decrease which also reduce the consumption of natural resources. Simultaneously, this postpones the production of construction debris which would benefit the environment.

But the remarkable point is that the development of cement-based products with the aid of nano-technology can greatly help their environmental compatibility. As discussed in the second section, with reducing the intensity of carbonation and ions leaching specially calcium, on one hand, we can postpone the degradation of these materials and on the other hand, prevent the environmental pollutions (especially ground water pollution). In a recently-done research (Gaitero, Campillo, & Guerrero, 2008), application of silica nano-particles with low dosages has improved the microstructure of cement matrix, and consequently leaching resistance of the specimens. As a result of this study, we can observe lower entrance of calcium ions into the ground waters, and to somehow, help the nature and humankind as well.

Also, nano-devices are tools for the development of nano-science. Accordingly, by using new nano-devices, more precise research on the structure of cement-based materials can be carried out to achieve better understanding on the basic properties of these materials. Thus, the performance of cement-based materials could be improved through the desired ways (Constantinides & Ulm, 2007; Monteiro, *et al*., 2009).

#### *3.1.2. Development Of Available Green Concrete Products:*

Green concrete is defined as a concrete which uses waste material as at least one of its components; or its production process does not lead to environmental destruction. On the other hand, as mentioned in the second section, the largest alternative for waste materials in concrete consists of aggregate, pozzolanic material, and filler. Accordingly, based on the results of the previous section (3-1-1), the development of green concrete industry could initiate. This means that applying nano-particles with the recycled concrete structures improved strength and durability, and consequently the consumption of these products has been raised in the construction industry. Moreover, if the high level of cement consumption (the most detrimental part of concrete production) can be reduced, then sustainable concrete may be achieved.

According to recent research, the application of silica nano-particles along sewage sludge ash (Kuo, Lin, Chang, & Luo, 2006; D. Lin, Lin, Chang, Luo, & Cai, 2008; K. Lin, Chang, Lin, Luo, & Tsai, 2008), high amounts of fly ash (G. Li, 2004), high amounts of natural pozzolan (Booshehrian, Madari, Hosseini, Vaezi, & Artin, 2010), recycled aggregate (Hosseini, Booshehrian, Delkash, Ghavami, & Zanjani, 2009; Hosseini, Booshehrian, & Madari, 2011) and waste tire rubbers (M.Karbalaie, Sohrabi, & Shafie, 2009) has been cited. Also, the properties of the cement paste with high levels of ground granulated blast furnace slag (GGBFS) and fly ash have been improved by using nano-sized $CaCO_3$ particles (Sato & Beaudoin, 2006; Sato & Diallo, 2010). In these cases, using nano-particles enhanced the strength and durability of green concrete specimens. This issue will produce specific recycled concretes such as SCC, HPC, UHPC or RPC reinforced with cement-based nano-composites in future investigations.

Also, nano-particles and nano-cement can be used to achieve certain strength levels by using smaller amounts of ordinary Portland cement. Because the use of these materials increased the strength and durability of concrete specimens which would be higher than the structural strength designed for the structures; therefore, by applying this material, lower cement content is required to achieve the same strength for the structure. Accordingly, researchers could reduce the amount of cement in concrete up to %20 without reducing the strength by using small amounts of silica nano-particles (alternative 2%) (Bahadori & Hosseini, 2011).

In addition, in a recently-done study, silica nano-particles have been also applied as developing factors for mechanical properties, durability, and microstructure of cement based composites and cement sheets reinforced with recycled natural fibers (Hosseinpour, Varshoee, Soltany, & Hosseini, 2011). Based on discussed issues, nano-particles can be used as a tool for achieving sustainable development in the concrete industry (Bahadori, Hosseini, & Eslami, 2009; Hosseini, *et al*., 2011).

The production and using of low energy cement is another issue that researchers have been considered. In this type of cement, level of belite ($C_2S$) is increased rather than high level of alite ($C_3S$). Applying high amounts of belite caused lower clinkering temperature and lower $CO_2$ emissions during the production process; this is largely due to the low calcium design of the clinker composition (Sui, Fan, Wen, Wang, & Zhang, 2004). Accordingly, these cements are also quite sustainable in terms of energy conservation and environment protection (Sui, *et al*., 2004). However, if the nano-particles are used for cement reinforcement, then it would contribute to the development of these types of cements. Since the early age strength of high belite cements is lower than conventional cement, using silica nano-particles can improve the early age strength of the cement to an appropriate rate; this is largely due to intense pozzolanic reaction. Furthermore, the use of nano alumina has improved the early age strength of belite cements (Campillo, *et al*., 2007).

Additionally, designation of modern types of clinkers which decrease the emission of $CO_2$ in the cement production process is one of green strategies in cement industry. Accordingly, sulfoaluminate clinker is known as a subcategory of clinkers with low $CO_2$ emissions (Alaoui, *et al*., 2007; Gartner & Quillin, 2007; Habert &

Roussel, 2009). Besides, by the aid of nanosicence and nanotechnology, if we try to produce Belite nano-cement, sulfoaluminate-based nano-cement, or a combination of these two cements, we will be able to considerably improve their performance and take a positive step towards reducing detrimental emission caused by cement production process.

***3.1.3. Development Of Novel Concrete Products:***

One of the advantages of nanotechnology is the production of products with smart properties. When nano-materials and nano-devices are used in concrete manufacturing, cement-based products with smart properties could be observed. Similarly, the application of some nano-particles has produced intelligent cement-based materials. Using $TiO_2$ nano-particles in formation of cement-based materials has led to producing self-cleaning materials (Cassar, 2004; Chen & Poon, 2009; Husken, Hunger, & Brouwers, 2009). These materials absorb pollution by their surface due to their photocatalytic characteristic; these impurities are then wiped when washing the surface. Some examples of pollution that are absorbed include: $NO_x$, CO, VOCs, chlorophenols, and aldehydes (Sanchez & Sobolev, 2010). Moreover, as a result of nano-particles in their structure, self-cleaning materials have acceptable strength and durability (H, *et al*., 2007; Jayapalan, *et al*., 2010; Jayapalan, *et al*., 2009; H. Li, *et al*., 2006) and thereby have a greater lifetime compared to conventional materials.

On the other hand, the application of $Fe_2O_3$ nano-particles in the manufacture of cement mortars contributes to decrease in the electrical resistance of concrete while higher structural loads are being applied; so, the electrical conductivity of concrete will be increased (H. Li, *et al*., 2004b). This characteristic aids the stress monitoring of the structure. Therefore, cement-based products having $Fe_2O_3$ nano-particles possess self-sensing property. Furthermore, as mentioned before, the strength and durability of concrete will increase with the application of $Fe_2O_3$ nano-particles. Moreover, utilizing nano-fibers can result in the production of smart cement composites (Chung, 2000). These materials can monitor the behaviour of the structure under the effect of various loadings; this can later be used as an important tool to check the health monitoring of structures (Han, Yu, & Kwon, 2009).

***3.2. Reduce Energy Consumption:***

Since energy is discussed almost as the most important commodity in global markets, its indiscriminate use would be unacceptable for governments in terms of economic, environmental and strategic aspects. Accordingly, a procedure should be adopted which enables us to help reduce the consumption of valuable natural resources by using clean energies and substituting them for fossil fuels. Of course, other ways such as improving the performance of applied machinery can lead to reduced fuel consumption. To achieve this goal, nano-materials that improve the performance of machinery for carrying the concrete components and the engine of trucks, bulk trailers, and truck mixers can be produced to optimize fuel consumption. On the other hand, as mentioned in section 3-1-2, the production of belite cements will result in the reduction of energy consumption during cement production (Sui, *et al*., 2004). Now, if the nano-belite cements are produced or reinforced with nano-materials, the early age strength of these cements will be increased. Additionally, according to section 2, by substituting the fossil fuels with waste fuels, the high volume energy consumption can be reduced (Dong & Lee, 2009).

Nowadays, the utilization of clean energies such as solar energy has attracted much attention. Since the application of nano-solar cells shows more suitable performance compared to conventional solar cells, it is possible to store and use much more solar energy by exploiting nano-solar cells (Graetz & Reilly, 2005).

***3.3. Monitoring Performance Of Concrete Products:***

Nowadays, nano-sensors are used to monitor structural behaviour; they are used to predict and examine the problems of structures (Saafi, 2004). It can lead to fast improvements in structures without the demand of major repairs or demolition. As mentioned before, in a certain period of time, resource demands, and residue production would be decreased. However, regarding the issues stated in section 3-1-3, using nano-particles and nano-materials can also produce smart concrete leading to performance monitoring of structure. The optical fiber-based sensors are applied for monitoring the performance of concrete structures (GF.Fernando, *et al*., 2003). Accordingly, the nano optical fiber-based sensors are used for monitoring the performance and strength development of concrete structures. More investigations can be done to develop the efficacy of these sensors and may operate as foundation for revolutionizing the monitoring of structural behaviour. On the other hand, the application of smart products based on nano-powders of piezoelectric ceramic (PZT) as monitoring tools is an interesting topic for further researches. Using smart PZT patches for the online monitoring of early-age strength development in concrete performed appropriate results (Shin & Oh, 2009).

***3.4. Reduce Environmental Pollutants:***

Since, at a certain time, the construction residues face lower production due to increase in structure lifetime, improvement of the concrete strength, durability and rheological properties which will reduce the destructive environmental effects of concrete. The other important issue is the production of concrete with photocatalytic characteristics. Also, nano-particles cause the improvement of photocatalytic characteristic in this type of concrete. The development of green concrete properties results in higher volume consumption of these materials due to higher interest of consumers, and, in the near future, green concrete structures will become popular in the construction industry. The development of green concrete products increases the consumption of waste materials made by the concrete industry and other industries. This issue stands against the destructive environmental effects of waste material in nature during transfer and disposal.

On the other hand, by developing the cement-based products and improving their strength with the aid of nano-technology, we will be able to reduce the carbonation and leaching intensity. Within different achievements of this strategy, we can mention longer service life of structures and preventing the formation of environmental pollutions like ground water pollution. In this way, we provide a suitable situation for better compatibility of cement-based composites with nature.

In addition, nano-filteration products have achieved considerable progress recently. These new filters can be installed on gas exhausts in cement factories. Also, by changing their features, they can absorb many polluting gases and prevent them from entering the atmosphere. On the other hand, nano-filters can purify waste water in order to use in the ready-mixed concrete factories. As a result, the water can be conserved in dry zones of the world. It should be noted that improving the performance of the machinery used during the life cycle of concrete products leads to reduced energy consumption in addition to reduced environmental pollution. Among these pollutions, air pollution and sound pollution have been cited.

### *4. Conclusions:*

In this paper, the performance of nanotechnology and application of nano-materials in green concrete technology have been reviewed. Also, the approaches toward improving the nano-technology involvement in the development of concrete industry through ecological sustainable development were discussed. Therefore, a brief expression of what was described in this paper is enumerated in the following:

- Nano-materials and nano-devices, the main products of nanotechnology, are the main technologies associating the concrete industry. Therefore, using these products should help move the concrete industry towards a green industry.
- Nanotechnology involvement in the concrete industry is categorized in three categories. These three categories are not the only ways that nanotechnology has been involved in the ecological sustainable development of concrete industry; however, these three categories are the key ways in helping the concrete industry to approach towards a green concrete industry. Reduced consumption of natural resources, including raw materials and energy, reduction of environmental pollution during the life cycle of concrete products, and performance monitoring of concrete structures in order to quickly solve problems in the structure to prevent major repairs are three effective routes for the development of the green concrete industry with nanotechnology.
- Concrete product development is the main access key to reduce resource consumption and environmental pollution. Development of concrete products includes the development of available concrete products, development of available green concrete products, and development of novel green concrete products. Available concrete products are enhanced by applying nano-materials; these nano-materials include nano-particles, nano-chemical additives, and nano-fibers in cement-based materials matrix. As a result, the performance of concrete products would be improved and thereby have a greater lifetime for structures. Therefore, materials consumption decreases. Also, postponing the replacement of alternative structures with current structures reduces energy consumption and construction waste which is produced by destroying existing structures. On the other hand, the application of nano-materials can help develop green concretes and also concretes with high volume decrease of cement. The development of low-energy cements as nano-belite cements or belite cements reinforced with nano-particles is cited as the other solution to develop green products. Moreover, the process of designing and manufacturing smart products by nanotechnology has increased significantly in the concrete industry. Self-claening and self-sensing products can be thought of as smart products. Self-cleaning products achieve adequate strength and durability and absorb pollution, especially air pollution. Smart products with self-sensing capabilities can monitor the behaviour of a structure and report their health, therefore leading to crisis management.

  A remarkable point which should be mentioned here is utilizing the computational nano-modelling as one tool aiding in examination of the properties of cement-based materials that can result in performance development of these composites.
- Taking advantage of nano-devices for understanding microstructural properties consequently improves the properties of cement-based products. In addition to using these instruments to improve the properties of cement-based materials matrix, the effect of any other materials used in the cement-based materials matrix could be monitored and investigated. Therefore, it gives the opportunity of changing these properties to a desirable level.

- According to the development of concrete products, especially green concrete products, the concrete industry is recommended as a recycling industry which converts waste materials to aggregate or powder. It contributes to less waste production of concrete industry and simultaneously reduces consumption of natural resources. Development of application of clean energy due to lack of pollution during the extraction and consumption is a step toward sustainable development. This issue can be developed based on particular advantage of energy-saving nano-composites. Application of nano-materials helps improve the performance of machinery used in production, transmission, and distribution components of concrete production by enhancing energy efficiency. In addition, it can prevent sound pollution and other types of pollution produced by these machines. Finally, application of nano-filters will be very useful for purifying waste waters such as runoff or sewage. In turn, the nano-filters reduce the amount of air pollutants entry during the concrete and cement production.

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