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An Investigation into the Role of Nano-Silica in Improving Strength of Lightweight Concrete

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Abstract

Development of technology and human's access to nanotechnology brings about the necessity to use nanotechnology in the concrete industry. Since the decrease of particles size leads to new and unusual mechanical, electrical, and magnetic properties which are inaccessible in usual state, nanotechnology is highly considered. The emergence of nanotechnology in concrete industry has made great changes in many of the concrete properties. Dead load resulted from weight of ceilings and separation walls is among the fundamental problems in seismic design and structures implementation especially in tall buildings. Obviously, using the lightweight materials could decrease the dead load, weight of beams, columns, and foundation. However, low compressive resistance of lightweight concrete mostly has a direct ratio with the specific gravity of it. Lightweight concrete has a low resistance as a result of its low specific weight. Silica nanoparticles (SNs) have a high surface energy as a result of their high specific surface. Therefore, they are supposed to have a high pozzolanic reaction and they accelerate hydration reactions. Since the increase of concrete compressive strength is highly noticeable in the new technology, the increase of effective materials with the purpose of increasing compressive strength of concrete could increase the life circle of concrete structures. The present paper intends to investigate the effect of silica nanoparticles on compressive strength, tensile strength, bending strength, contraction of lightweight concrete, and concrete microstructure.

Key terms- Lightweight Concrete; Silica Nanoparticles; Pozzolanic Reaction

Introduction

Dead load resulted from weight of ceilings and separation-walls is one of the fundamental problems in seismic design and implementation of structures. Obviously, using lightweight materials decreases dead load and consequently, it decreases weight of beams, columns, and foundation. However, low compressive strength of lightweight concrete limits the possibility to use it in structural members (Kumar and Monteiro, 2006). Since mechanical properties of concrete mostly has a direct ratio with its specific gravity, low specific gravity of lightweight concrete causes its less compressive strength. Therefore, the researchers constantly try to improve mechanical properties of lightweight concrete by using additives for the lightweight concrete. Since the decrease of particles size leads to new properties, and unusual mechanical, electrical, and magnetic properties which are inaccessible in usual state, nanotechnology is highly considered. One of the reasons for emergence of unusual properties is that the atomic size of particles dimensions causes the considerable increase of number of atoms located in the aggregates boundary in comparison with the particles mass. Moreover, the ratio of particles specific surface to the total volume increases and causes increase of particles activities and vey-high reactivity. Furthermore, the manipulation of atoms arrangement in nano-scale could change their basic properties and have access to materials which have characteristics such as strength, corrosion resistance, color resistance, and so forth (Roc, 2004).

Familiarity with lightweight concrete

Lightweight concrete refers to concretes whose specific gravity in dry state varies between 300 to 1850 kg per cubic meter (specific gravity of ordinary concrete approximately equals 2400 kg per cubic meter) (Florence Sanchez, Konstantin Sobolev, 2010). Lightweight concretes are categorized into two groups regarding their application, the first group is structural lightweight concretes, and the second one is non-structural lightweight concretes. According to Iran concrete regulation, structural lightweight concrete should have a 28-day compressive strength more than 160 kg per square centimeter. However, non-structural lightweight concretes are mostly used to construct separation walls, floors, and so forth. Low strength of lightweight concrete is an important factor that restricts applications of lightweight concrete. A resistant lightweight concrete with proper physical properties and improved weight brings about a great evolution in application of the mentioned concrete. Generally, there are three methods to produce lightweight concrete. In the first method, light porous materials with a low apparent specific gravity are used instead of conventional aggregates. The obtained concrete is called lightweight concrete. The second method is producing lightweight concrete by making various pores within the concrete or mortar. The mentioned pores should be distinguished from very fine pores filled with air bubbles; this kind of concrete is known as “foamed concrete”, “gas concrete”, and “aerated concrete”. The third method of producing lightweight concrete refers to omitting fine aggregates from the mixture so that many pores could be created among particles and coarse concretes with usual weight could be consumed. This type of concrete is called” no-fines concrete” (Florence Sanchez, Konstantin Sobolev, 2010).

Structural lightweight concrete

Structural lightweight concrete is defined as a concrete with specific gravity that varies from 1400 to 1900 kg per cubic meter and minimum compressive strength for it equals 17 Newton per square mm. the structural lightweight concretes have an adequate strength and specific gravity so that they could be applied in structural members. Constructing such concretes is merely possible by using lightweight and strong aggregates. All structural lightweight concretes are categorized in the group of lightweight aggregate concretes in which lightweight aggregates are used in order to decrease the concrete specific gravity. Therefore, the concepts of lightweight aggregate concrete and structural lightweight concrete are synonymously used.

In structural lightweight concretes, the applied aggregates have strength over 17 mega pascal and a specific gravity less than 2000 kg per cubic meter (Hoseinzadeh, Azad, 2012).

An introduction into nanoscience

Nonoscience play an important role in producing innovative concretes in the 21st century. Nanoscience enables scientists to work at atomic and molecular levels in order to produce new materials with new physical and chemical properties. Nanomaterials refer to materials that at least, one of its dimensions is less than 100 nm. With regard to issues such as strength, resistance, durability, and high performance, the construction industry is one of the important users of nanomaterials. A nanomaterial refers to a solid whose atomic arrangement, size of its crystals, and its chemical composition could be extended in a multi-nanometer scale. Physical and chemical properties of nanomaterial should not be considered alike with microscopic materials. There are fundamental differences between nanomaterials and microscopic materials and these changes include their small size as well as their new properties at nanoscale level. The final purpose of the present paper is to study materials at nanoscale in order to find a new high-performance categorization of construction materials. Such construction materials are called multi-purpose and high-performance materials. The multi-purpose performance refers to emergence of new and different properties in comparison with the normal properties of materials (Janbozorgi and Qanad, 2010).

Nano silica

Nano silica is the most abundant material that makes the earth. It has the chemical composition of $Si0_2$ which is similar to a diamond structure. It is a white and crystal-formed material. Nano silica is one of the most applied nanoparticles in concrete. It is a new pozzolanic material which is in water in a solid or liquid form. In the concrete industry, nano silica is one of the most famous materials that determine viscosity and filling state of the concrete. According to figure 1, nano silica is made up of bullet-formed particles with diameter less than 100 nanometer, or dry-powder particles, or particles which could be dispersed in the liquid. The researchers pay attention to nano silica as one of the products of nanotechnology that plays an important role as a very active pozzolan in the concrete. Adding nanoparticles of concrete could maintain its strength during physical and chemical reactions and also compress the particles (Gengying Li, 2004).

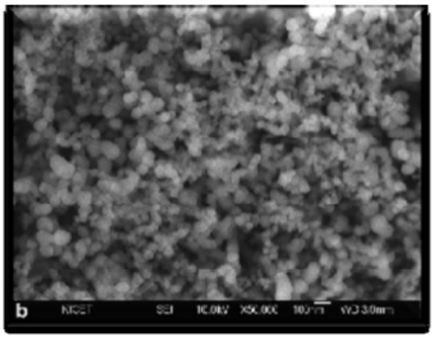

Figure 1: SEM image of nano silica

Nano-cements including nano silica

The concrete mixture contains fumed silica and it is known as a great corrector of the concrete structure durability when it is exposed to corrosive salt. Generally, adding fumed silica that plays the role of an additive in nanoscale leads to constructing durable concrete, however, if it is added more than the needed amount, the concrete will be brittle. Therefore, the amount of adding it should be determined (Kalvandi, 2008). Silica is one of the most famous materials that play an important role in viscosity and filling related to the high performance concrete (HPC). The ordinary product of microsilica fume (microsilica) has a diameter of 0.1 to 1 mm and it has silicon oxide up to 90 percent. Nano silica has the most application in self compact concrete (SCC) construction. Nano silica has a density of 0.15 g/cm, purity degree of 99.9, cross section of approximatrly 15, and properties such of being anti-slip, fire-resistant, and abrasion resistant. Results of studies indicate that adding 3 percent of nano silica to the cement molar results in decrease of size of CH crystals, therefore, crystals finds a folded state. Consequently, the common surface of reactants will be more than cements with silica fume and it will have a higher resistance (Kalvandi, 2008).

Nano silica reaction in lightweight concrete

When particles' size reaches nanoscale, particles' specific surface increases and number of atoms on the surface rapidly increase. The presence of atoms on the surface with these dimensions brings about free links with the rest of the capacity force which is unstable. On the other hand, the decrease of grain size causes high degrees of atomic inequalities. These atomic inequalities intensify chemical reactions. Therefore, nanoparticles such as nano silica have higher surface energy and the activities of atoms at the surface are higher and they could have internal reaction with other external atoms.

Intelligent concrete

Concrete is an intelligent material and it has a regular activity. When one thinks about the microstructure of concrete and how its particles are combined, a better understanding of it will be achieved. In the research studies done in FHWA institute, the nuclear resonance reaction analysis (NRRA) is used to study cement hydration at nanoscale. As a result, more information is achieved regarding the hydration of cement particles. A beam of nitrogen-atoms is shined to the cement to which the water is added, and then the results are depicted in the form of a graph. The graph is called in-depth hydrogen profile and it indicates the speed of water penetration and arrangement of different surface layers which have been obtained through the reaction (Kalvandi, 2008). The surface layer has a thickness of 20 nanometers and it acts like a semi-permeable dam and it let the water penetrate cement particles and react with calcium ions. Silica ions which are larger will be caught at the back of the layer. The continuity of the reaction makes a silicate gel under the surface layer and the mentioned gel is the cause of cement swelling, consequently, the surface layer suddenly breaks. The break releases the trapped silicates and it reacts to the calcium ions, produces calcium-silicate-hydrate (C-S-H) gel, and hardens the concrete. Gradual completing of hydrogen profile indicates the time of surface layer breaking. The information could be studied for investigating hardening process as a function of temperature, heat, chemistry, cement, and so forth. For instance, breaking of hydrated cement at 86 degrees of Fahrenheit for 1.5 hours is determined via NRRA after increasing water (Kalvandi, 2008).

Today, researchers apply sensors at nanoscale for concrete mixing. The sensors which are related to the central computer transfer all of their surrounding information. For instance, if this kind of concrete is applied in a bridge, the sensor will transfer all of the relevant information such as traffic load volume, and location of the crack to the central server. Therefore, the manager of urban traffic control will easily understand whether there is a heavy traffic or fluent traffic on the mentioned bridge. On the other hand, if the concrete bridge confronts any difficulty, the sensors which are in relation with the central computer will transfer the information.

Figure2: Schematic samples of nano-sensors and the condition of their combination at nanoscale

Currently, another concrete is in the construction phase, in this concrete the organic carbon is added to the concrete mix to make it intelligent for a certain period of time. Such a concrete could react to the cracks (Kalvandi, 2008).

The main purpose of the present paper is to study the role of nanosilica in improving strength of lightweight concrete. Moreover, the secondary purposes of the present paper have been mentioned as follows:

- An investigation into the effect of nanosilica on compressive strength of lightweight concrete
- An investigation into the effect of nanosilica on tensile strength of lightweight concrete
- An investigation into the effect of nanosilica on bending strength of lightweight concrete
- An investigation into the effect of nanosilica on microstructure of lightweight concrete

Materials and methods

In order to collect data, library method has been used. In fact, library method is applied in order to collect data in the field of internal and external studies background. The descriptive-analytical study of effect of nanosilica on improving strength of lightweight concrete has been done by studying specialized magazines, collected data, and other researchers' studies.

Results and discussion

Role of nano silica in improving strength of lightweight concrete

The effect of nano silica on lightweight concrete has been studied in a research done by Khastehband and colleagues (2009). The investigation was done based on constructing different laboratorial samples containing colloidal nano-silica solution at different ages and comparing them with resistance properties of the control sample without nano-silica along with microstructure studies and SEM pictures. Silica is the most important cement pozzolanic composition that reacts to the calcium hydroxide resulted from cement hydration and produces hydrated calcium-silicate gel which is the main factor of concrete strength. The speed of pozzolanic reaction depends on the reaction accessible surface (Porro et al., 2005). Since nano silica has a very high specific surface, it is able to do the pozzolanic reaction very well. Therefore, adding a little amount of it to the concrete could considerably affect the increase of compressive and tensile strengths in the lightweight concrete. Moreover, a study on SEM pictures indicates the higher compression of samples that contain nano silica in comparison with the control sample. The results of tests have been represented as follows:

Compressive strength test

Results of the compressive strength test at the ages of 1,3,7, and 28 days indicate the noticeable increase of compressive strength at all ages and with regard to different percents of replacing nano silica. In fact, this issue results from the highly noticeable pozzolanic activity of nano silica. It seems that very fine sizes of nano-silica particles produce great surfaces. In these surfaces, the capability to do high pozzolanic activities has been provided, consequently, nano silica particles react to the released calcium hydroxide resulted from water- cement hydration operation and C-S-H gel is produced. C-S-H gel was known as the main material that causes strength of the concrete paste (Qing et al., 2005).

In order to use nanomaterials especially nano silica in concrete, it should be noticed that using nano silica in concrete brings about the severe problem of water shortage in concrete (Li et al., 2002). This issue causes the decrease of concrete flow state, makes it hardened, and causes the slamp of the concrete. When higher percents of nano-silica are used, the compression at the time of molding is not done perfectly especially in the case of lightweight concrete whose grains are brittle. Therefore, in order to solve the molding problem and the shortage of water in the concrete, very strong super-plasticizers must be used within the concrete. The more the amount of nano silica in the concrete causes the more need for superplasticizer within the concrete. However, it has been observed that using superplasticizers cannot solve the problems where high percents of nano silica have been used in the concrete. In such cases, stronger superplasticizers are needed to compensate the shortage of water in the concrete (Khastehband et al., 2009).

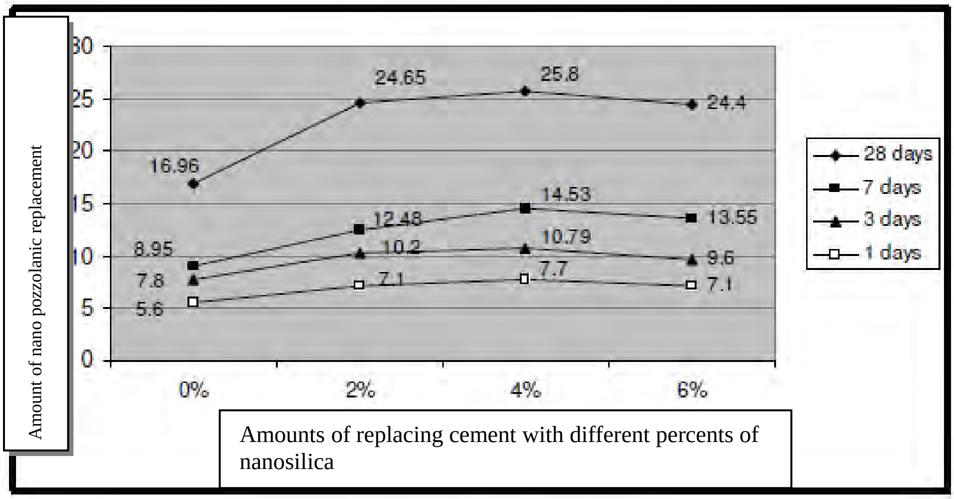

Figure 3: Compressive strength based on the amount of nano pozzolanic replacement at different ages

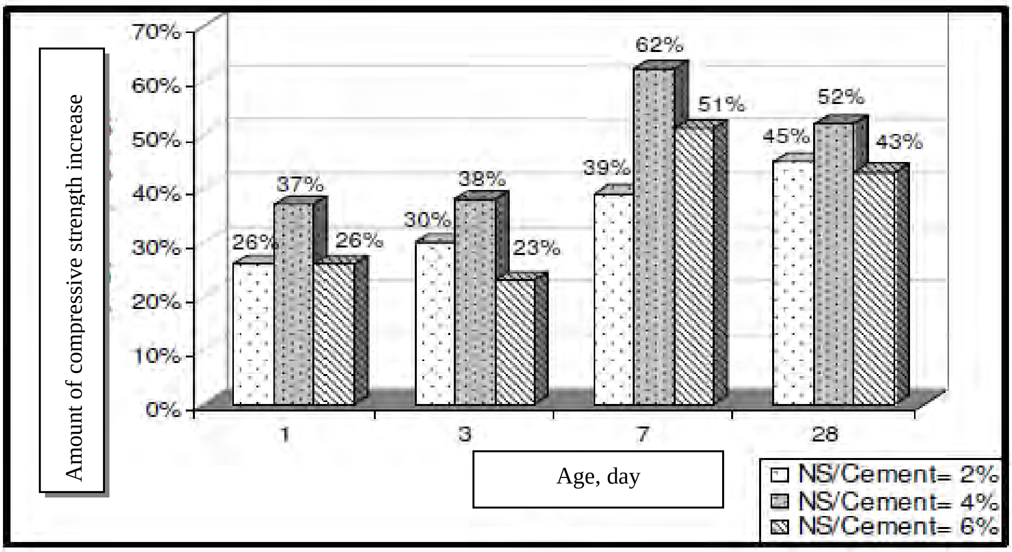

Figure 4: The amount of compressive strength increase in samples that contain nano silica in comparison with control sample at different ages

Tensile strength test

Results of tensile strength test indicate the increase of tensile strength of samples with nanosilica in comparison with the control sample. However, the increase of nano silica up to 6 percent does not cause a considerable effect on the tensile strength of the sample with nano silica and it is because of the fact that the increase of higher amounts of nano silica causes the brittleness of the concrete (Khastehband et al., 2009).

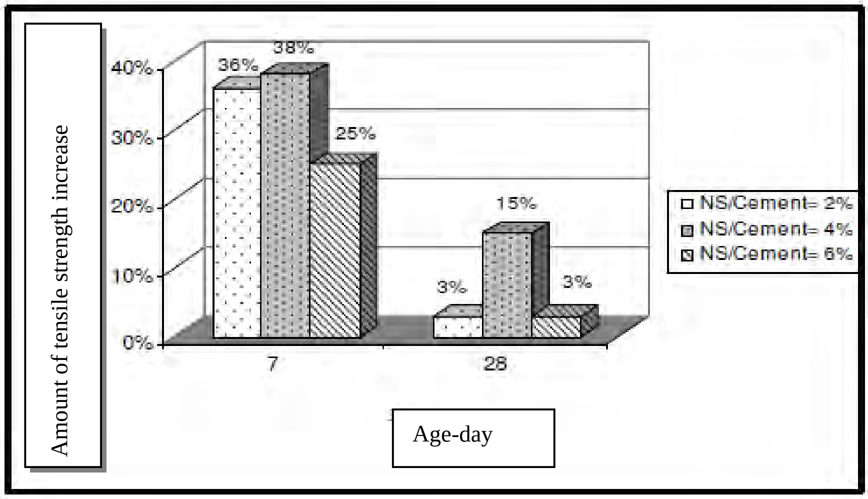

Figure 5: the amount of tensile strength increase in samples that contain nano silica in comparison with control sample at different ages

SEM pictures analysis

With regard to figures 6 and 7, in the samples with nano silica especially the sample with 4 percent of nanosilica, the microstructure of the lightweight concrete has a higher compression.

The size and number of microstructural pores in samples with nano silca are less than that of the control sample; moreover, the compression of concrete paste in samples with nano silca indicates the positive impact of the pozzolan on the concrete. The investigation of figures 8 and 9 confirms the above results. According to figure 9, number and size of calcium hydroxide crystals with a large crystal structure and a hexagonal prism in the control sample are more than that of samples with nano silica in figures 8 and 9. In samples with nano silica, making a reaction between nano silica and calcium hydroxide causes the absorption of a part of crystals by the concrete and the size and number of them decrease. Results of tests and SEM pictures indicate that nano silica improves microscale structures of the concrete because of the fact that pictures related to microscale structures in the lightweight concrete containing nano silica is more homogeneous than the ordinary lightweight concrete, consequently, it improves concrete resistance properties (Khastehband et al., 2009).

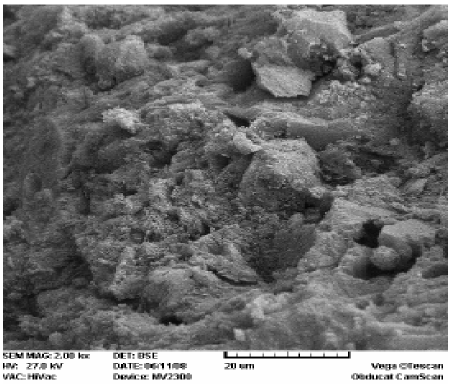

Figure 6: SEM picture of the sample containing 4 percent of nano silica (resolution=2000)

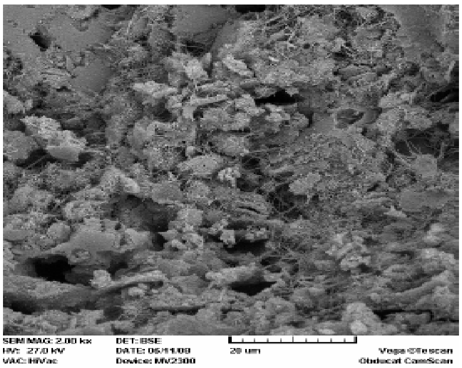

Figure7: SEM picture of the control sample (resolution= 2000)

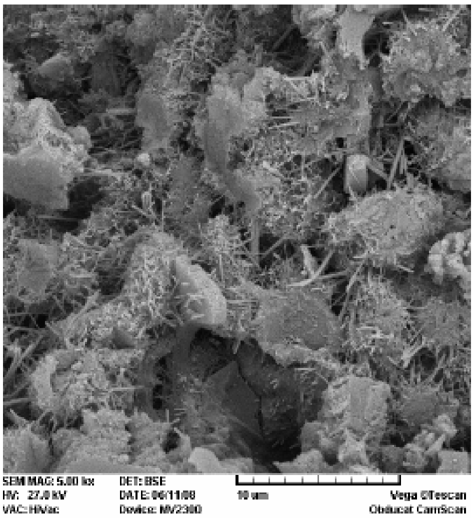

Figure 8: SEM picture of the sample containing 2 percent of nano silica (resolution= 5000)

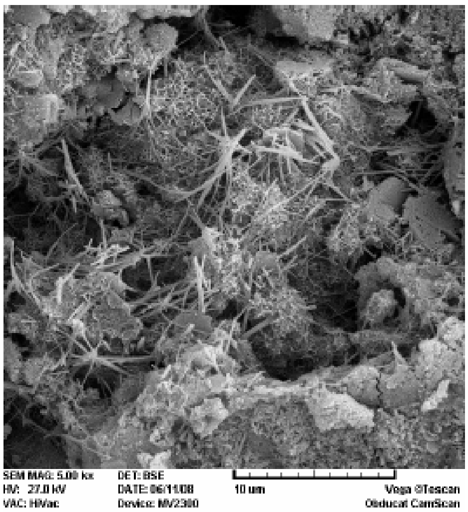

Figure 9: SEM picture of the control sample (resolution= 5000)

Conclusion

Properties, behavior, and performance of the concrete depend on the nanostructure of the cement and concrete that creates viscosity, and uniformity. Therefore, concrete and cement paste studies at nanoscale is very important for development of new construction material and their applications. Using nanotechnology in concrete occurs by adding nano-additives such as nanosilica, nano-iron, and so forth. Moreover, nanotechnology is a way to make changes in microstructure of cement particles, chemical properties, and physical properties of it. According to studies done in China related to the impact of nanoparticles on tensile and compressive strengths of mortar of cement, adding nanoparticles of iron and cilica particles to the cement mortar improves tensile and compressive strengths in comparison with the ordinary mortar. Moreover, it is possible to make anti-radiation and anti-nuclear effects structures that could save energy.

The following results have been obtained through investigation the role of nano silca in improving strength of the lightweight concrete:

- High strength concretes could be constructed by using nanotechnology.
- The increase of cement strength is the most important advantage of nanoparticles. When particles are uniformly distributed in the molar, nanoparticles fill the cement pores, and also they act as a core which strongly sticks to the hydrated cement. As a result of its intense activity, the cement hydration is done rapidly and the cement strength increasers. Therefore, this process is used in strengthening highly-important structures and repairing cracks.
- The electrical resistance will increase when iron nanoparticles are added to the concrete mix during increasing the load. In fact, iron nanoparticles are semi-conductor and absorb the energy. This process could also be used for structures that need the constant control and optimization and their behavior is constantly controlled.
- Nanotechnology is used to repair structures which are subjected to corrosion. Therefore, cement paste will have a better efficiency and mechanical and physical properties by adding nano silca to it. The results indicate that majority of nano-cements increase the strength of concrete and it is vital for the strength of structures.
- The nanoparticles could be applied in order to obtain the lightweight concrete with very low penetrability.
- Nanotechnology increases the durability of concrete. In other words, it decrease carbonation risk, penetration of chlorine and so forth.

According to the comparison of nano silica and micro silica, the following results have been achieved:

- In comparison with micro silica, the impact of nano silica on strength is more rapid as a result of its higher specific surface.
- Pozzolanic activity of nano silica during the primary ages is better than micro silica.
- Nano silica improves cement paste, fills its pores, accelerates hydration as a pozolanic material with high reactivity that reacts to unstable crystals of calcium hydroxide, increases strength and viscosity of C-S-H gel structure by decreasing size of crystals, and finally it increases the strength of concrete.

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